

# CENTRAL VALLEY FLOOD MANAGEMENT PLANNING PROGRAM

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## Public Draft

2012 Central Valley Flood Protection Plan

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## Attachment 8B: Reservoir Analysis

January 2012

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# 1.0 Introduction

This section provides the purpose of this attachment, background information (including planning areas, goals, and approaches), an overview of flood management in the Central Valley, past and ongoing reservoir operations studies, and report organization.

## 1.1 Purpose of this Attachment

As part of preparation of the Central Valley Flood Protection Plan (CVFPP), potential management actions were developed for flood management in the Central Valley; these management actions were evaluated and combined into various approaches. One of the management actions considered for the 2012 CVFPP was to increase flood management flexibility in major multipurpose reservoirs in the Sacramento and San Joaquin river basins. This flexibility could be accomplished through a variety of methods such as changes to reservoir operational criteria, construction of new reservoirs, or physical modifications to existing reservoirs. For the 2012 CVFPP, only changes in reservoir operational criteria (i.e., flood storage allocation and objective release) were considered to provide downstream flood management benefits for this reconnaissance-level analysis.

Because the potential to realize flood management benefits from changing reservoir operational criteria was uncertain, the 2012 CVFPP Reservoir Analysis was performed to first determine if there was any opportunity associated with operational criteria changes. The objective of the analysis described in this attachment was to demonstrate whether there is any potential improvement in systemwide flood management (e.g., lower downstream peak flood stage) from changes to reservoir operational criteria. Results from this analysis provide insight for more detailed and coordinated studies to explore operational criteria changes.

Implementing reservoir operational criteria changes for real-world operations is complicated and has wide-spread implications. Because most of the flood management reservoirs in the Central Valley are operated for multiple purposes, changing operational criteria for flood management benefits may have unintended effects on other reservoir purposes (e.g., water supply, hydropower). In addition, changes to the operational criteria of an individual reservoir can affect how other reservoirs operate. The complicated and interconnected nature of these flood management

reservoirs makes it imperative that willing reservoir owners and operators, and the U.S. Army Corps of Engineers (USACE), who have jurisdiction over reservoir flood operations, coordinate. Any changes would also require coordination among ongoing reservoir studies such as the California Department of Water Resources' (DWR) existing Forecast-Coordinated Operations (F-CO) Program, planned Forecast-Based Operations (F-BO) Program, and ongoing System Reoperation Program. In addition, to implement such changes would require a detailed project-level feasibility study to evaluate effects on other reservoir purposes, followed by significant administrative actions.

Therefore, because of the preliminary and exploratory nature of the 2012 CVFPP Reservoir Analysis, it is an initial assessment of potential reservoir-related opportunities to support the 2012 CVFPP development. This analysis does not propose any specific changes to current reservoirs operations be made or suggest that these changes are the only options for modifying operational criteria. The 2012 CVFPP Reservoir Analysis is a preliminary analysis of opportunities and effects with a systemwide perspective, and future studies are needed to more thoroughly consider other potential effects (e.g., water supply, environmental, hydropower) and the feasibility of modifying operational criteria at individual reservoirs.

For modeling purposes, this preliminary analysis considered a few potential scenarios to improve systemwide flood management flexibility, which were included in the Enhance Flood System Capacity Approach for the 2012 CVFPP (see Section 1.5, below). Reservoir operational criteria changes were ultimately not moved forward into the State Systemwide Investment Approach because of: (1) the preliminary nature of this analysis; (2) uncertainty associated with the potential effects of reservoir operational criteria changes; and (3) the need to coordinate with operators and owners on more detailed, reservoir-specific analyses. An exception is the already authorized operational changes associated with the Folsom Dam Raise, which are included in both the No Project condition and State Systemwide Investment Approach.

## **1.2 Background**

As authorized by Senate Bill 5, also known as the Central Valley Flood Protection Act of 2008, the DWR has prepared a sustainable, integrated flood management plan called the CVFPP, for adoption by the Central Valley Flood Protection Board (Board). The 2012 CVFPP provides a systemwide approach to protecting lands currently protected from flooding by existing facilities of the State Plan of Flood Control (SPFC), and will be updated every 5 years.



As part of development of the CVFPP, a series of technical analyses were conducted to evaluate hydrologic, hydraulic, geotechnical, economic, ecosystem, and related conditions within the flood management system and to support formulation of system improvements. These analyses were conducted in the Sacramento River Basin, San Joaquin River Basin, and Sacramento-San Joaquin Delta (Delta).

### 1.3 CVFPP Planning Areas

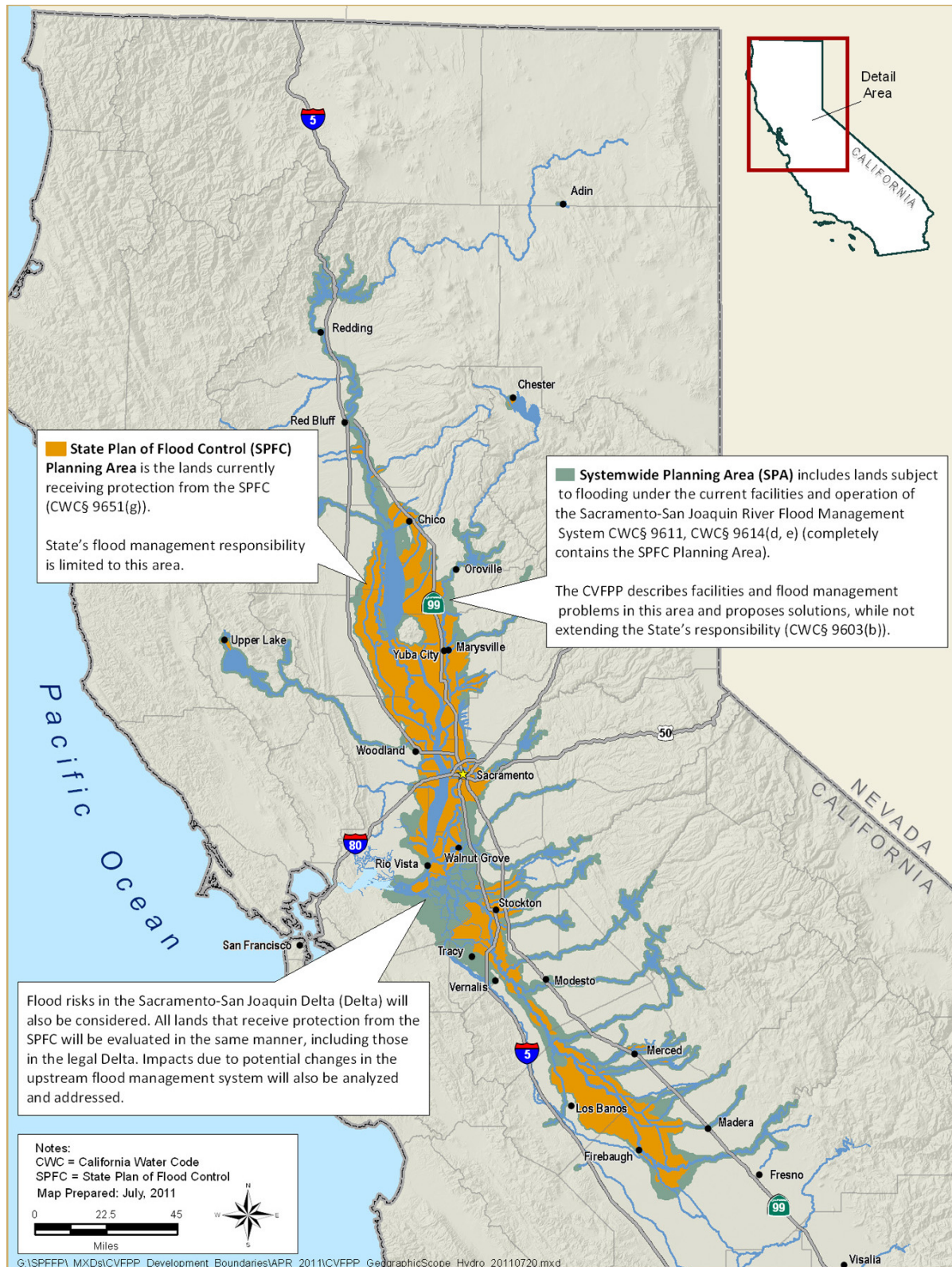
For planning and analysis purposes, and consistent with legislative direction, two geographical planning areas were important for CVFPP development (Figure 1-1):

- **SPFC Planning Area** – This area is defined by the lands currently receiving flood protection from facilities of the SPFC (see *State Plan of Flood Control Descriptive Document* (DWR, 2010b)). The State of California's (State) flood management responsibility is limited to this area.
- **Systemwide Planning Area** – This area includes the lands that are subject to flooding under the current facilities and operation of the Sacramento-San Joaquin River Flood Management System (California Water Code Section 9611). The SPFC Planning Area is completely contained within the Systemwide Planning Area which includes the Sacramento River Basin, San Joaquin River Basin, and Delta regions.

Planning and development for the CVFPP occurs differently in these planning areas. The CVFPP focused on SPFC facilities; therefore, evaluations and analyses were conducted at a greater level of detail within the SPFC Planning Area than in the Systemwide Planning Area.

The 2012 CVFPP Reservoir Analysis focused on major multipurpose reservoirs located within the Systemwide Planning Area. Because this analysis built on the approach, models, and data developed for the Comprehensive Study (USACE, 2002a), the Delta and Mokelumne, Cosumnes, and Calaveras rivers and small streams that enter the Delta were not part of the planning area for the 2012 CVFPP Reservoir Analysis, because they were not a primary focus of the Comprehensive Study. While this analysis did not specifically quantify flood management benefits solely within the SPFC Planning Area, the scenarios were compared using locations that were generally within the SPFC Planning Area.

**2012 Central Valley Flood Protection Plan  
Attachment 8B: Reservoir Analysis**



**Figure 1-1. Central Valley Flood Protection Planning Areas**

## 1.4 2012 CVFPP Planning Goals

To help direct CVFPP development to meet legislative requirements and address identified flood-management-related problems and opportunities, a primary and four supporting goals were developed:

- **Primary Goal** – Improve Flood Risk Management
- **Supporting Goals:**
  - Improve Operations and Maintenance
  - Promote Ecosystem Functions
  - Improve Institutional Support
  - Promote Multi-Benefit Projects

The goal of the 2012 CVFPP Reservoir Analysis was to explore the potential to improve flood risk management on a systemwide level by changing reservoir operational criteria to improve operational coordination among the reservoirs, thereby lowering downstream peak water levels.

## 1.5 2012 CVFPP Planning Approaches

In addition to the **No Project** approach, three fundamentally different approaches to flood management were initially compared to explore potential improvements in the Central Valley. These approaches are not alternatives; rather, they bracket a range of potential actions and help explore trade-offs in costs, benefits, and other factors important in decision making. The approaches are as follows:

- **Achieve SPFC Design Flow Capacity** – Address capacity inadequacies and other adverse conditions associated with existing SPFC facilities, without making major changes to the footprint or operation of those facilities.
- **Protect High Risk Communities** – Focus on protecting life safety for populations at highest risk, including urban areas and small communities.
- **Enhance Flood System Capacity** – Seek various opportunities to achieve multiple benefits through enhancing flood system storage and conveyance capacity.

Comparing these approaches helped identify the advantages and disadvantages of different combinations of management actions, and demonstrated opportunities to address the CVFPP goals to different degrees.

Based on this evaluation, a **State Systemwide Investment Approach** was developed that encompasses aspects of each of the approaches to balance achievement of the goals from a systemwide perspective, and includes integrated conservation elements. Figure 1-2 illustrates this plan formulation process.

The 2012 CVFPP Reservoir Analysis used the No Project condition as a baseline for reservoir operational criteria. The scenarios considered in this analysis were included as elements of the Enhance Flood System Capacity Approach, but were ultimately not moved forward into the State Systemwide Investment Approach because detailed studies and extensive coordination are needed. The only reservoir operational criteria change included in the State Systemwide Investment Approach is the authorized Folsom Dam JFP.

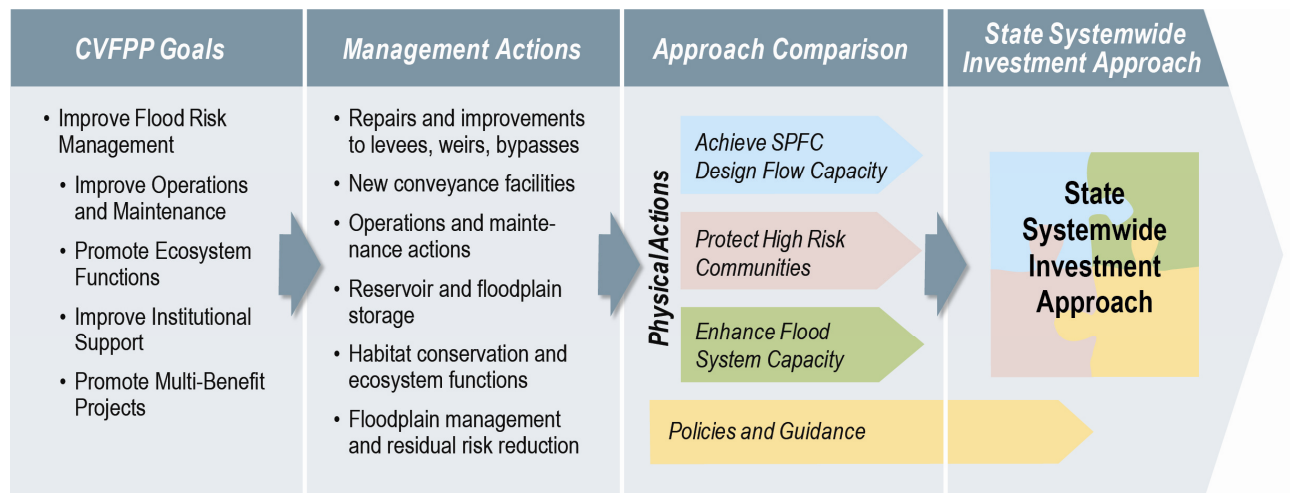


Figure 1-2. Formulation Process for State Systemwide Investment Approach

## 1.6 Overview of Flood Management in the Central Valley

The Central Valley of California encompasses watersheds of its two major river systems, the Sacramento River in the north and the San Joaquin River in the south. These basins drain more than 43,000 square miles, and the rivers come together in the Delta and discharge to the Pacific Ocean through San Francisco Bay.

Because of the climate and geography of the Central Valley, flooding is a frequent and natural event. Major flooding on the Sacramento and San Joaquin river systems has been documented since the mid-1800s, and has resulted in the loss of lives and massive property damage. This has prompted various planning efforts by State, federal and local entities over the last century and resulted in structural (i.e., construction of physical structures such as dams and reservoirs) and nonstructural (i.e., regulation of floodplain development) efforts. Development of multipurpose reservoirs began in 1932 with authorization of the Central Valley Project (CVP). Multipurpose reservoirs are operated to meet various objectives, such as flood management, water supply, and environmental requirements. The last major flood management facility to be completed was New Melones Reservoir in 1979. Despite improvements to flood management in the Central Valley, damages from flooding have continued, leading to the perceived need for further actions.

Major multipurpose reservoirs in the Sacramento and San Joaquin river basins considered for this analysis are listed in Table 1-1. Note that multipurpose reservoirs located on the eastside tributaries (e.g., Camanche Reservoir) are not included in this table or analysis because hydrologic routing tools are not yet available for those tributaries that enter the San Joaquin River within the boundaries of the Delta. More details on assumptions about reservoirs analyzed are contained in Section 3 of this report. Figure 1-3 is a schematic illustrating the location of the major multipurpose reservoirs considered for this analysis (highlighted in magenta) in relationship to the overall system. The figure shows the size, ownership, and flood management classification for every reservoir in the Sacramento and San Joaquin river basins.

**Table 1-1. Major Multipurpose Reservoirs in Sacramento and San Joaquin River Basins Considered in this Analysis**

Reservoir	River	Gross Pool Storage (TAF) <sup>1</sup>	Maximum Flood Space (TAF) <sup>1</sup>	Owner	Year Completed
<b>Sacramento River Basin</b>					
Shasta Dam and Shasta Lake	Sacramento River	4,552	1,300	Reclamation	1949
Oroville Dam and Lake Oroville	Feather River	3,538	750	DWR	1968
New Bullards Bar Dam and Reservoir	Yuba River	966	170	YCWA	1970
Folsom Dam and Lake	American River	977	670	Reclamation	1956
<b>San Joaquin River Basin</b>					
Friant Dam and Millerton Lake	San Joaquin River	521	170 <sup>2</sup>	Reclamation	1949
Buchanan Dam and H.V. Eastman Lake	Chowchilla River	150	45	USACE	1975
New Exchequer Dam and Lake McClure	Merced River	1,025	350 <sup>2</sup>	Merced ID	1967
New Don Pedro Dam and Lake	Tuolumne River	2,030	340	TID/MID	1970
New Melones Dam and Lake	Stanislaus River	2,420	450	Reclamation	1979

Source: adapted from USACE, 1999

Notes:

<sup>1</sup> Storage and flood management space values are rounded to the nearest 1,000 acre-feet.

<sup>2</sup> Maximum flood management space may vary depending on upstream storage and/or snowpack.

Key:

DWR = California Department of Water Resources

Merced ID = Merced Irrigation District

MID = Modesto Irrigation District

Reclamation = U.S. Department of the Interior, Bureau of Reclamation

TAF = thousand acre-feet

TID = Turlock irrigation District

USACE = U.S. Army Corps of Engineers

YCWA = Yuba County Water Agency



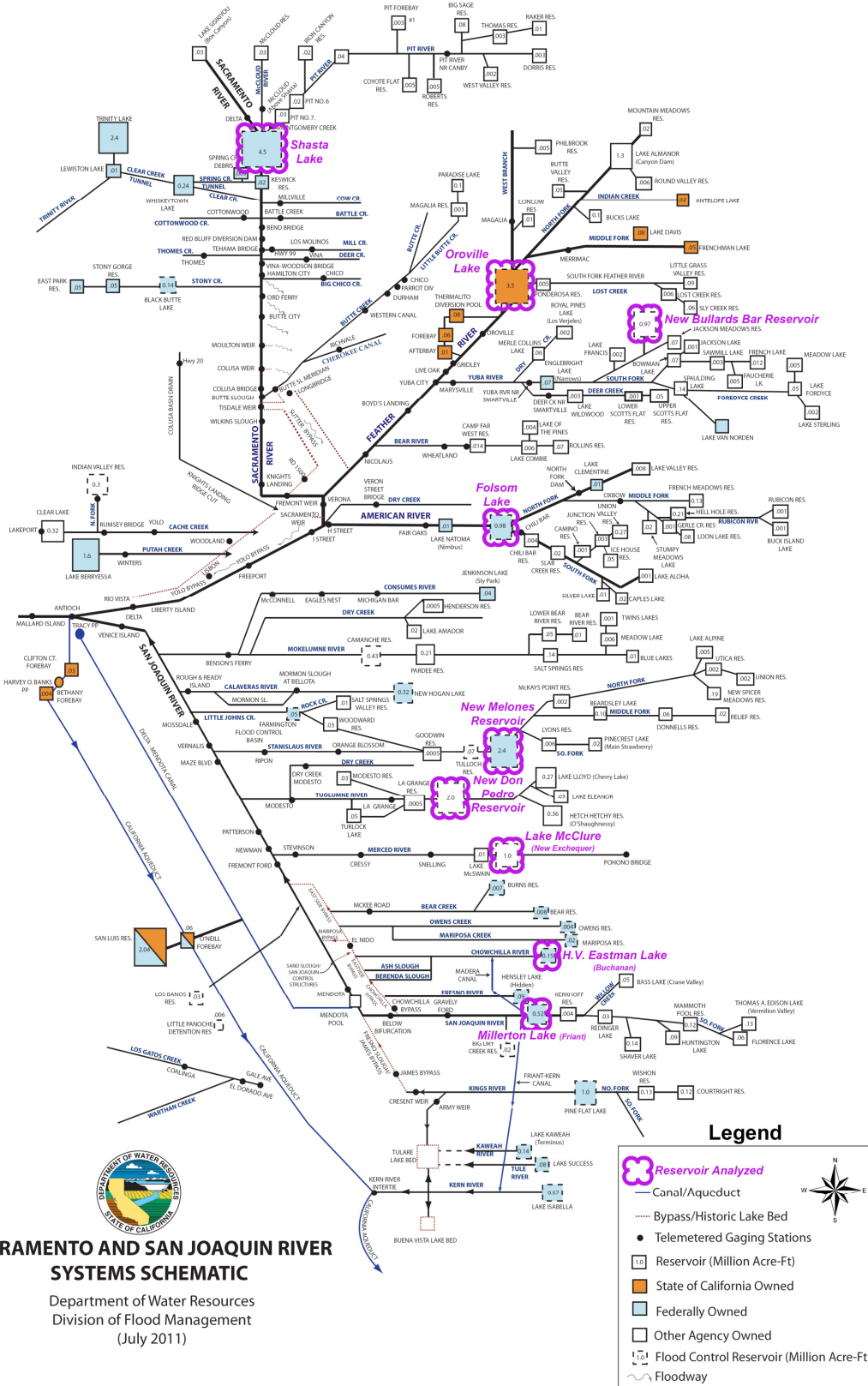


Figure 1-3. Sacramento and San Joaquin River Systems Schematic

## 1.7 Past and Ongoing Central Valley Flood Reservoir Studies

Numerous investigations regarding flood management reservoirs in the Central Valley have been completed or are ongoing. Most of these flood management reservoirs operate for multiple purposes and changes to any aspect of the reservoir often directly or indirectly affect its flood management operations even though the change may focus on one of the reservoir's other purposes (e.g., water supply, hydropower). In addition, changes to the operational criteria of an individual reservoir can affect how other reservoirs operate. The complicated and interconnected nature of these flood management reservoirs makes the coordination between studies imperative. This section highlights a few of the major studies that State and federal governments are participating in that may affect flood management operations and were considered in the 2012 CVFPP Reservoir Analysis.

### 1.7.1 2002 Sacramento and San Joaquin River Basins Comprehensive Study

The Comprehensive Study was a joint effort by the Reclamation Board of California (the predecessor of the Board) and USACE, in coordination with State, federal, and local organizations to develop a comprehensive plan for flood damage reduction and ecosystem restoration along the Sacramento and San Joaquin rivers following disastrous floods in January 1997. The Reclamation Board and USACE began working together in 1998 to prepare a comprehensive plan for the combined watersheds of the Sacramento and San Joaquin river basins (USACE, 2002a).

One of the major undertakings of the Comprehensive Study was to develop analytical tools to evaluate how changes to the system would affect the performance of the system as a whole with respect to reducing flood damages, protecting public safety, and restoring degraded ecosystems. The following are examples of computer modeling tools developed under the Comprehensive Study (USACE, 2002b):

- Synthetic hydrology
- HEC-5 reservoir operations models
- UNET hydraulic models
- FLO-2D hydraulic models
- HEC-FDA economic models

These computer modeling tools have the capability to evaluate how broad changes to the system affect its overall performance and to potentially redirect impacts to other parts of the system. Further refinement of these



models could support future planning for regional changes to the flood management system. Reservoir modeling is documented in Technical Studies Documentation Appendix C of the Comprehensive Study (USACE, 2002d).

The tools and methodology developed for the Comprehensive Study were used as a basis for this analysis with updates, as necessary (see Section 3). While new tools and hydrology are being developed by DWR, they were not available for use in the 2012 CVFPP Reservoir Analysis.

The Comprehensive Study synthetic hydrology and hydraulic models were also used for the 2012 CVFPP. Refer to Attachment 8A: Hydrology and Attachment 8C: Riverine Channel Evaluations, respectively, for more details.

### **1.7.2 Forecast-Coordinated Operations Program**

The goal of the F-CO program is to improve flood protection and better protect life and property for communities downstream from flood management reservoirs by reducing peak flood flows through better river flow forecasting and improved coordination. The key to improving flood protection is the coordination of local, State and federal operations during major flood events. This coordination is further enhanced through use of a decision support system and state-of-the-art technology for flood forecasting. The F-CO program allows water managers to operate the reservoirs in advance of and during major flood events with an improved level of forecast certainty, thus reducing peak river flows and the risk of exceeding river channel capacity. The F-CO program also improves notification processes and increases flood warning times to emergency operation managers, State and local offices of Emergency Services, levee districts and the downstream areas in danger of major flooding. Partners in the F-CO program include the California-Nevada River Forecast Center, USACE and reservoir operators.

This non-structural program has been implemented on the Yuba-Feather system as a pilot project and has proven to be one of the most cost-effective flood management improvement measures (described below). Following the success of the Yuba-Feather pilot project, DWR is currently expanding the F-CO program into the San Joaquin River watershed. DWR is currently in the early stage of partnering with some of the reservoir operators in the San Joaquin system.

The F-CO program can be coordinated with operational criteria changes to improve the efficiency by which reservoir storage is managed thereby minimizing potential impacts on the reservoirs' multiple purposes, and to

improve flood protection by maximizing their flood management operations.

### ***Feather-Yuba Forecast-Coordinated Operations***

The Feather-Yuba F-CO program began in 2005 to improve flood protection and better protect life and property for communities along and downstream from the Yuba and Feather rivers without impacting the water supply of Lake Oroville and New Bullards Bar Reservoir. The primary objective of the program is to reduce peak floodflows through improved river flow forecasting and improved coordination between Lake Oroville and New Bullards Bar Reservoir (YCWA, 2008).

This program is a cooperative effort by the Yuba County Water Agency (YCWA), DWR, the National Oceanic and Atmospheric Administration (NOAA), and USACE. Under this program, State, federal, and local operations during major flood events will be further enhanced through use of a decision support system and flood forecasting technology; thus, river peak flows and the risk of exceeding channel capacity could be reduced.

The Feather-Yuba F-CO program has completed the following two phases:

- **Phase 1 for design** – To identify and develop tools to improve the quality of flood forecasting and information technology needs.
- **Phase 2 for implementation** – To install 19 remote gaging stations with telemetry systems that transmit data to the California Data Exchange Center. After installation of the gages, efforts will focus on developing a reservoir operations model and integrating the model with the National Weather Service River Forecasting Center system.

The coordinated operation resulting from the Feather-Yuba F-CO program was included as part of the No Project condition (see Section 3).

### **1.7.3 Forecast-Based Operations Program**

After significant progress is made in F-CO program implementation, the next potential opportunity is an F-BO program. Pursuit of F-BO will be based on the interest of the reservoir operators.

The concept of F-BO allows for pre-releasing or storing water based on forecasted reservoir inflows, while taking into consideration the uncertainty of the forecasted inflows and the associated risks of spills and water supply deficits. Such operations more likely require changes in the reservoir flood control manual. The F-BO phase of the project involves (a) the use of forecasting, and (b) proactive reservoir management policies, guidelines,

and rules whose use may reduce flood damages associated with extreme events and improve water management operations. The California Nevada River Forecast Center is currently developing the collaborative forecasting capabilities. Concurrently, the F-CO program has funded the USACE's Hydrologic Engineering Center (HEC) to enhance the HEC-ResSim model to handle collaborative reservoir inflow forecasts.

The need for congressional authorization of the F-BO program will not be definitely determined prior to development of specific modifications/changes to the flood control manual, so the program is planned to be implemented in two steps. Step one will be to develop the program and document specific reservoir operation modifications, and consult with the USACE. During this step, the scope of the flood control manual's required modifications and the need for congressional authorization will be identified. Step two, if required, is to seek congressional authorization for the implementation of the F-BO.

While the F-BO program has not been implemented, future F-BO can be coordinated with reservoir operational criteria changes. This coordination has the potential to improve the efficiency with which reservoir storage is managed, thereby improving flood management.

### **1.7.4 Central Valley Hydrology Study**

DWR, under the FloodSAFE Initiative, and in cooperation with USACE, has initiated the Central Valley Hydrology Study, a comprehensive assessment of unimpaired and impaired Central Valley stream flow frequencies and magnitudes. This endeavor includes the development of a comprehensive database of historic rainfall and runoff information, the development of operation models for major Central Valley reservoirs, and an assessment of the effects on the hydrology from climate change. Previous systemwide hydrologic studies, such as the Comprehensive Study, completed a reconnaissance-level analysis of the system. These new Central Valley studies will extend the Comprehensive Study by providing the level of detail required for Federal Emergency Management Agency (FEMA) actions, feasibility planning studies, design of flood management actions, and studies and actions that will enhance operation of the existing flood management system.

The Central Valley Hydrology Study is under development and cannot be used for the 2012 CVFPP Reservoir Analysis. Once the hydrology is available, future studies can use the hydrology to perform their analyses.

### 1.7.5 Folsom Dam Joint Federal Project

Folsom Dam and Lake, components of the CVP, are owned and operated by the U.S. Department of the Interior, Bureau of Reclamation (Reclamation). The facility is primarily operated to maximize flood management and water supply storage benefits. It is also operated for power, fish and wildlife management, recreation, navigation, and water quality purposes (Reclamation, 2009).

To improve public safety, Folsom Dam and its appurtenant structures (collectively referred to as the Folsom Facility) must be strong enough to withstand the various types of forces and stresses created by a significant earthquake, storm, or seepage event. The authorized Folsom Dam Joint Federal Project (JFP) is a joint effort between Reclamation and USACE to address these issues at the Folsom Facility. The following three objectives are pursued as part of the Folsom Facility improvements:

- **Dam Safety** – the need for expedited action to reduce hydrologic (flood), seismic (earthquake), and static (seepage) events.
- **Flood Damage Reduction** – the need to reduce the risk of flooding in the Sacramento area, which is one of the most at-risk communities in the nation.
- **Increase Spillway Capacity** – provide improved flood protection to the lower American River watershed in conjunction with downstream levee improvements.

Construction activities began in January 2008 and will continue through 2015. These improvements will allow more water to be safely released earlier in a storm event, leaving more storage capacity in the reservoir to hold back peak inflows.

Because the Folsom Dam JFP is already authorized and under construction, this project was included as part of the No Project condition (see Section 3). San Joaquin River Restoration Program

The SJRRP is a comprehensive long-term effort to restore flows to the San Joaquin River from Millerton Lake at Friant Dam to the confluence of the Merced River and restore a self-sustaining Chinook salmon fishery in the river while reducing or avoiding adverse water supply impacts from restoration flows.

Implementation of the SJRRP would affect the timing and volume of Millerton Lake releases and potentially carryover storages. This program, while not intentionally changing flood operations, may incidentally affect

flood management benefits, especially when paired with reservoir operational criteria changes.

### **1.7.6 Surface Storage Investigations**

To address new water resources needs in California, the State and federal governments have funded five Surface Storage Investigations, which were conceived to support at least three of CALFED's programmatic goals: water supply reliability, water quality, and ecosystem restoration.

These new projects are being designed to be adaptive and robust, and would support aquatic and riparian ecosystem restoration focused on the Delta and its tributaries, improved drinking and habitat water quality, and the water supply needs associated with California's growing population and diverse economy. Furthermore, these projects must perform well under a number of potential future conditions including changing environmental conditions and needs, climate change, alternative Delta conveyance and management, and disaster/emergency response scenarios (DWR, 2012).

The five surface storage investigations are as follows:

- Shasta Lake Water Resources Investigation (Shasta Enlargement)
- North-of-the-Delta Offstream Storage (Sites Reservoir)
- In-Delta Storage Program
- Los Vaqueros Reservoir Expansion
- Upper San Joaquin River Basin Storage Investigation (Temperance Flat Reservoir)

These surface storage investigations (with the exception of the In-Delta Storage Program) will change the configuration of the Central Valley river systems and affect how flood management operations occur. These projects are not included in the 2012 CVFPP Reservoir Analysis because they are still in their early planning stages, but are important as they may affect future operational criteria change studies.

### **1.7.7 Federal Energy Regulatory Commission Relicensing**

FERC relicensing does not typically affect flood operating rules, which are prescribed by USACE for federal projects or as a condition of federal cost sharing on nonfederal projects. But, FERC relicensing may change how water is released and the timing and magnitude of inflow into downstream

major multipurpose reservoirs, thus having an incidental effect on flood operations.

Reservoirs that have hydropower facilities are regulated through licenses that FERC issues for given periods of time. As the expiration date of an existing license approaches, dam owners must undergo FERC relicensing, which involves reviewing operational practices of the overall facility to continue operation of the hydropower facilities.

Per the 1986 Federal Power Act, FERC is required to develop license conditions with equal consideration of development and environmental values. The FERC relicensing process provides an opportunity for public and resource agencies to evaluate project effects and balance needs from different perspectives, as well as to modify hydropower dams to meet modern environmental standards. New licenses establish new requirements for water supply, flood management, water quality, fisheries, wildlife, recreational uses, cultural resources, etc. Implementation of these requirements is unlikely to change reservoir flood management operational criteria.

The FERC relicensing process takes multiple years to complete. At least 5 years before a license expires, the licensee must file a notice of intent to file a new license and submit a preapplication document with a proposed study plan to begin the scoping process for an environmental analysis. At least 2 years before a license expires, the licensee must file an application for a new license, and FERC begins the environmental analysis.

In the Central Valley, several reservoirs are undergoing the relicensing process, including Lake Oroville, Middle Fork American River Project, New Bullards Bar Reservoir, New Don Pedro Reservoir, New Exchequer Reservoir, and Mammoth Pool. Lake Oroville, an SPFC facility, is owned by DWR and is operating under an annual license issued by FERC effective on February 1, 2007. Through the FERC relicensing process, the Oroville Facilities were to reevaluate all project purposes and to accommodate current issues that were not extant when the first 50-year license was issued in 1957. One such issue is the potential effects of the facility on spawning Chinook salmon; this will be mitigated through the use of the Oroville Facilities Chinook Salmon Fish Hatchery (DWR, 2010a).

FERC relicensing may change how water is released and the timing and magnitude of inflow into downstream major multipurpose reservoirs, thus having an incidental effect on flood operations and potentially the benefits associated with operational criteria changes.

## 1.8 Report Organization

Organization of this document is as follows:

- Section 1 introduces and describes the purpose of this attachment. It also provides an overview of flood management in the Sacramento and San Joaquin river systems, and past and ongoing Central Valley flood reservoir studies that affect reservoir operational criteria and form a basis for this analysis.
- Section 2 summarizes results and findings of 2012 CVFPP reservoir modeling in the Sacramento and San Joaquin river basins and future opportunities for reservoir analyses after 2012.
- Section 3 describes the methodology used in this analysis.
- Section 4 describes the current (No Project) performance of multipurpose reservoirs in the Sacramento and San Joaquin river basins.
- Section 5 describes the sensitivity of the system to reservoir operational criteria changes that were used to identify scenarios for further consideration.
- Section 6 explores two operational scenarios considered for the 2012 CVFPP.
- Section 7 summarizes the simulated flood management benefits of the scenarios considered.
- Section 8 contains references for the sources cited in this document.
- Section 9 lists acronyms and abbreviations used in this document.

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## 2.0 Results Summary and Findings

Model results from this preliminary analysis conducted for the 2012 CVFPP, suggest that there are potential systemwide flood management benefits that could result from allocating more space to flood storage and from modifying release schedules, especially when operational criteria changes reduce downstream peak flood stage. It is recommended that future detailed and coordinated studies occur to consider other potential effects (e.g., water supply, environmental) and to explore the feasibility of modifying operational criteria at individual reservoirs.

While this analysis does not propose any specific changes to reservoir operational criteria or suggest that these changes are the only options for modifying operational criteria, the 2012 CVFPP Reservoir Analysis does provide insight for future studies to explore operational criteria changes in more detail. This analysis highlighted the following observations:

- Operational criteria changes are generally effective in lowering downstream peak flow and, as a result, the volume of water leaving a channel through levee breaches.
- While operational criteria changes can reduce peak downstream flood flow, the changes in peak flow are not necessarily consistent for all frequency storm events or for all storm locations (centerings).
- Delaying larger reservoir releases could allow floodwater from other tributaries to pass through the Central Valley flood management systems before the modified reservoirs release their higher flow, generally resulting in lower downstream peak flows.
- The volume of additional flood storage allocation is not equal to the actual reduction in out-of-system flow volume (e.g., an additional 100 TAF of flood storage allocation does not reduce the volume of out-of-system flow by 100 TAF). Therefore, from the viewpoint of containing out-of-channel flood volume, an increase in flood storage allocation may not be as efficient as other methods.

In general, physical or operational criteria changes could reduce the need for some types of downstream actions, such as levee improvements, and could mitigate the hydraulic effects that system improvements can have on downstream reaches. Reservoir operational criteria changes can also provide greater flexibility to accommodate future hydrologic changes, (e.g., climate change), provide greater system resiliency, and benefit the ecosystem.

While changes to flood storage allocations and objective releases typically require relatively small capital costs, they could have significant water resources impacts and present regulatory challenges. Because of the interconnected nature of the multipurpose reservoirs in the Central Valley, changes to flood management operations will affect operations for other purposes (including water supply, hydropower generation, and recreation). To implement such changes would require a detailed project-level analysis and coordination to develop a comprehensive suite of analyses, followed by significant administrative actions. The 2012 CVFPP recommends an overall system reservoir analysis to holistically evaluate potential integrated solutions, such as the one DWR is currently formulating under its System Reoperation Program.

## **2.1 Inclusion in 2012 CVFPP Approaches**

The preliminary findings from this analysis were included in the Enhance Flood System Capacity Approach. This approach includes modifications to the reservoir release schedule and flood storage allocation at Lake Oroville (equivalent to an additional 200,000 acre-feet of flood storage), and coordinated operation with New Bullards Bar Reservoir, to reduce flood stages on the Feather River during a 200-year (0.5 percent annual exceedance probability (AEP)) flood event. Also, in the San Joaquin River Basin, the State would partner with interested reservoir operators to increase the flood storage allocation at New Don Pedro, Friant, and/or New Exchequer dams by about 400,000 acre-feet to effectively manage the 100-year (1 percent AEP) flood event at these reservoirs. In combination with bypass expansion and other features of the Enhance Flood System Capacity Approach, these operational features help manage the timing and magnitude of peak floodflows before they enter the Sacramento and San Joaquin rivers.

Operational criteria changes were ultimately not moved forward into the State Systemwide Investment Approach because of: (1) the preliminary nature of this analysis; (2) uncertainty associated with the potential effects of operational criteria changes; and (3) the need to coordinate with operators and owners on more detailed, reservoir-specific analyses. An exception is the already authorized operational changes associated with the Folsom Dam Raise, which are included in both the No Project condition and State Systemwide Investment Approach.

## 2.2 Potential Future Studies

The 2012 CVFPP Reservoir Analysis described herein provides insight for future evaluations, and these future reservoir operational criteria studies should focus on the development of integrated solutions that consider project-specific costs as well as addressing potential effects on other reservoir purposes. The integrated solutions could include actions such as increasing downstream transitory storage, constructing setback levees, and increasing upper watershed storage to maximize flood management and other benefits.

Conjunctive use (CU), which is the cooperative management of both surface water and groundwater, is another possibility to be explored in future reservoir analyses. By diverting water from a flood management reservoir into a groundwater aquifer prior to flood season, CU could increase flood protection by providing additional flood storage allocation in the reservoir, but could still recover the prestored water if needed during the year. Combining this CU analysis, with other systemwide analyses would aid in formulating and selecting reservoir operational criteria change alternatives. These future studies should also be coordinated with ongoing studies such as DWR's existing F-CO and planned F-BO programs.

As stated above, the 2012 CVFPP Reservoir Analysis used existing data and tools to explore modifications to the reservoir operational criteria of flood storage allocation and objective release. In addition to reservoir operational criteria changes, other actions (such as increasing transitory storage, constructing setback levees, and increasing upper watershed storage) that maximize flood management benefits while providing other benefits should be explored to identify integrated flood management solutions. Various efforts have been made and others are underway to analyze the potential for reservoir operational criteria changes in further detail.

In summary, with the defined vision from the 2012 CVFPP, future reservoir analyses could include, but not be limited to, the following:

- **Hydrology Updates** – New hydrology is being developed for the Sacramento and San Joaquin river basins under the Central Valley Hydrology Study. This new hydrology will be used to prepare new inflow hydrographs for the HEC-5 (or HEC-ResSim) models.
- **Climate Change** – Current inflow hydrographs for the HEC-5 models were developed based on historical data and climate

information. Climate change may modulate the “typical” hydrology<sup>1</sup> and alter the timing and evacuation requirements for flood management; thus, it is necessary to incorporate climate projections into reservoir operational criteria. Once DWR identifies a standardized approach for climate change, hydrology could be updated to address climate change. In addition, a better understanding of changes in the timing and distribution of precipitation and runoff within the State would improve decisions regarding operational criteria changes, as well as the ability to assess systemwide effects of operational criteria changes.

- **Reservoir Modeling Tools** – The HEC-5 models from the Comprehensive Study, provide a basin-wide representation of Central Valley multipurpose reservoirs, and a prefeasibility tool to identify ranges of operational criteria change scenarios for future analysis. Project-specific reservoir analyses will require reservoir models with additional details for in-depth evaluations. New models could be developed or adapted for analysis in the future.
- **System Optimization** – Future analyses could aim to apply an optimization approach to identify optimal alternatives under interconnected operational criteria constraints (e.g., water supply, flood management operations, and hydropower generation constraints).
- **Headwater Reservoir Operations** – Headwater reservoirs are mainly for hydropower generation, and mostly have no formal flood management functions. However, previous studies have indicated that available storage in headwater reservoirs could significantly reduce peak inflows into lower basin reservoirs (USACE, 2002d). Changes in headwater reservoir operations could potentially reduce flood damage through spillway regulation or alteration of outlet elevations to better account for flood operations.
- **Offstream Storage Opportunity** – Diverting excess floodflows from river channels into adjacent storage areas could reduce flow rate and stage within the main channels. Refuge or agricultural areas along the mainstem Sacramento and San Joaquin rivers could provide such offstream storage for flood damage reduction. These

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<sup>1</sup> Hydrologic impacts of climate change are uncertain, but are likely to increase hydrological variability in the future and include less frequent precipitation, more intense precipitation, increased frequency of dry and extremely wet days, and less snowpack and snow cover. Precipitation shifts would affect the origin and timing of runoff. Increases in precipitation intensity could increase flood events, and thus change the overall flood regime (such as the frequency of different sized floods) and affected areas (Brekke et al., 2009).

storage projects would provide opportunities to allocate or reallocate dedicated flood storage space or change operational criteria to meet flood damage reduction objectives.

- **Physical Reservoir Modifications** – The 2012 CVFPP Reservoir Analysis only explored the potential of altering reservoir operational criteria, not physical modifications. To minimize the effects on the other purposes of the reservoirs (e.g., water supply reliability, hydropower generation, recreational opportunities, groundwater storage, instream requirements), physical modifications to the dams and reservoirs should be considered in future analyses. For example, increasing the size/capacity of a reservoir would provide additional flood storage without reducing the current water supply storage.
- **Starting Storage Assumptions** – This analysis assumed that the starting storage for each reservoir was the top of conservation pool. Especially for lower frequency storms, starting storage may be lower than assumed in this analysis. Future analyses should explore the potential benefits and impacts of operational criteria changes under various reservoir starting storages.

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## 3.0 Methodology

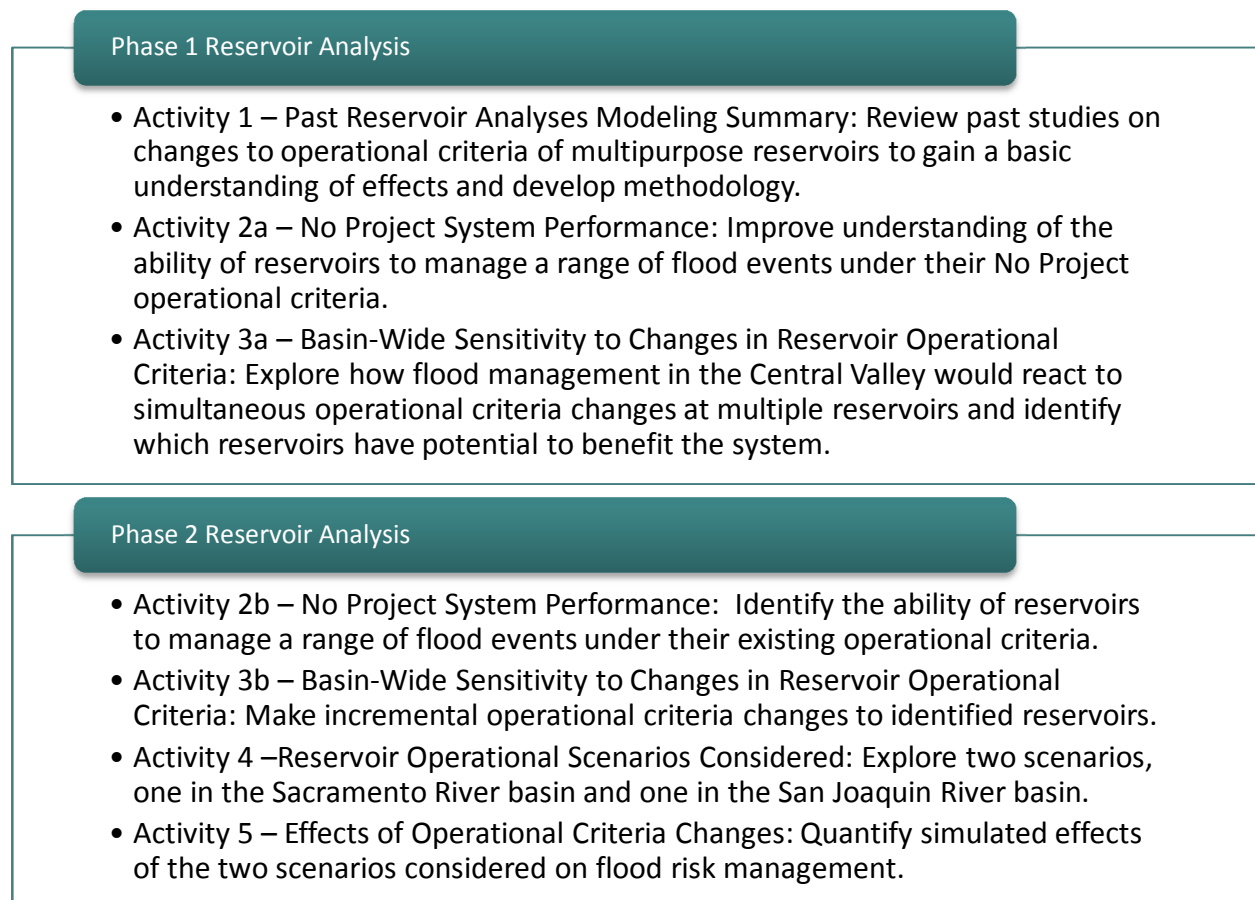
This section first provides an overview of the approach used for the 2012 CVFPP Reservoir Analysis. Then it summarizes past reservoir studies on changes to operational criteria, whose methodology and tools were used as a starting point for the 2012 CVFPP Reservoir Analysis. The remainder of the section discusses the assumptions, model selection, and model specifications used in the 2012 CVFPP Reservoir Analysis.

### 3.1 2012 CVFPP Reservoir Analysis Approach

The 2012 CVFPP Reservoir Analysis was separated into two phases and conducted as five different activities. Phase 1 reviewed past studies on changes to operational criteria (Activity 1), explored the current ability of reservoirs to manage a range of flood events (Activity 2a), and identified a range of reservoir operational criteria changes that could potentially reduce peak flow along the mainstem rivers for further analysis in Phase 2 (Activity 3a). Phase 1 of the 2012 CVFPP Reservoir Analysis did not identify any reservoir-specific changes in reservoir operational criteria, but did identify potential types of operational criteria changes, such as enlargement of flood storage allocation or modifications to reservoir release criteria, for future analysis in Phase 2.

The objectives of Phase 2 were to further explore and identify the current (No Project) ability of reservoirs to manage flood events (Activity 2b), perform incremental operational criteria changes based on Phase 1 observations (Activity 3b), explore operational scenarios (Activity 4), and estimate benefits and impacts from the scenarios (Activity 5). Phase 2 explored two scenarios, one in the Sacramento River Basin and one in the San Joaquin River Basin, that have potential to help reduce downstream floodflows, thereby increasing flood management flexibility.

Figure 3-1 outlines the two phases and briefly describes the activities conducted in each phase. Each type of activity is grouped together and described in separate sections in this report.



**Figure 3-1. 2012 CVFPP Reservoir Analysis Flowchart**

## 3.2 Past Reservoir Analyses Modeling Summary

Prior to the 2012 Reservoir Analysis, one other study that analyzed flood management in both the Sacramento and San Joaquin river basins from a systemwide perspective was the Comprehensive Study. Before the Comprehensive Study, studies focused on making incremental changes to the system without fully understanding how they might affect other parts of the system and the performance of the system as a whole. Because of similar objectives and systemwide perspective, the 2012 CVFPP Reservoir Analysis used the Comprehensive Study models and data as a basis for the analysis, with updates as necessary to include modifications to flood management in the Central Valley after the Comprehensive Study was completed. The models were then used to evaluate potential systemwide flood management effects from changing reservoir operational criteria for the 2012 CVFPP.



### **3.2.1 Comprehensive Study Background**

The goal of the Comprehensive Study was to develop a comprehensive plan for flood damage reduction and ecosystem restoration along the Sacramento and San Joaquin rivers. A major part of the study was to develop analytical tools capable of evaluating the effects of changes on performance of the system as a whole with respect to reducing flood damages, protecting public safety, and restoring degraded ecosystems.

The Comprehensive Study reservoir modeling used HEC-5 as the reservoir simulation software. Extensive efforts were made to collect data and input flood management operational criteria into HEC-5 models to accurately represent without-project conditions. Detailed HEC-5 reservoir modeling was then performed to evaluate various flood management alternatives, including the following categories (USACE, 2002d):

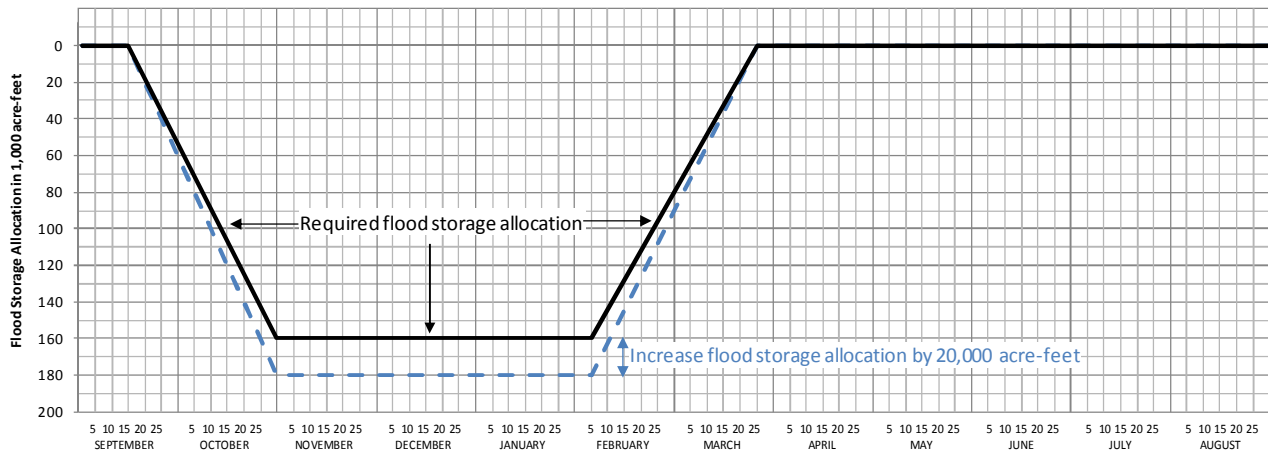
- Operational criteria changes to lower basin reservoirs
  - Grid analysis that varied flood storage and objective releases of individual reservoirs
  - Reservoir operational criteria changes of existing reservoirs
  - Incorporation of floodplain storage areas in the San Joaquin River Basin with reservoir operational criteria changes
- Operational criteria changes to headwater reservoirs
- Use of onstream and offstream storage

These evaluations were completed by modifying the assumptions in the HEC-5 base models (e.g., increasing available flood storage allocation, decreasing objective release criteria) and running the models for storms of various AEPs and centers. Potential effects resulting from the Comprehensive Study alternatives were evaluated by comparing peak flows at control points for the alternative conditions against without-project conditions assuming that a reduction in peak flow could decrease flood damage. Details of the reservoir operation modeling are documented in Comprehensive Study Technical Studies Documentation Appendix C (USACE, 2002d).

The rest of this subsection provides a results summary of various flood management operation alternatives. These preliminary findings from the Comprehensive Study helped guide the 2012 CVFPP Reservoir Analysis.

### 3.2.2 Grid Analysis

The Comprehensive Study lower basin reservoir analysis included performing a grid analysis to evaluate how incremental changes to an individual reservoir's flood management storage and/or objective release affect the ability to manage flood events of various frequencies. Both the flood storage allocation and the objective release were changed incrementally (individually and in combination) for a range of values. The flood storage allocation was changed by lowering the required top of conservation pool on the flood rule curve (see Figure 3-2 for an example). The solid and dotted lines represent the minimum amount of required space with and without flood storage allocation changes, respectively, to be kept in the reservoir at all times. For each modification, changes in peak reservoir outflow rates under different storm events were evaluated.



**Figure 3-2. Example Flood Management Diagram**

In HEC-5, the required flood storage allocation for a targeted reservoir was increased (or decreased) by lowering (or raising) the top of conservation pool; no changes to the reservoir size were made. With a larger flood storage allocation, the reservoir could store a larger volume of inflow before it reached the gross pool, thus delaying or even eliminating emergency spillway releases that were higher than the objective release. Additional storage allocation could increase flood protection and help meet objective flows (therefore maintaining flows at or below channel capacity) during larger events.

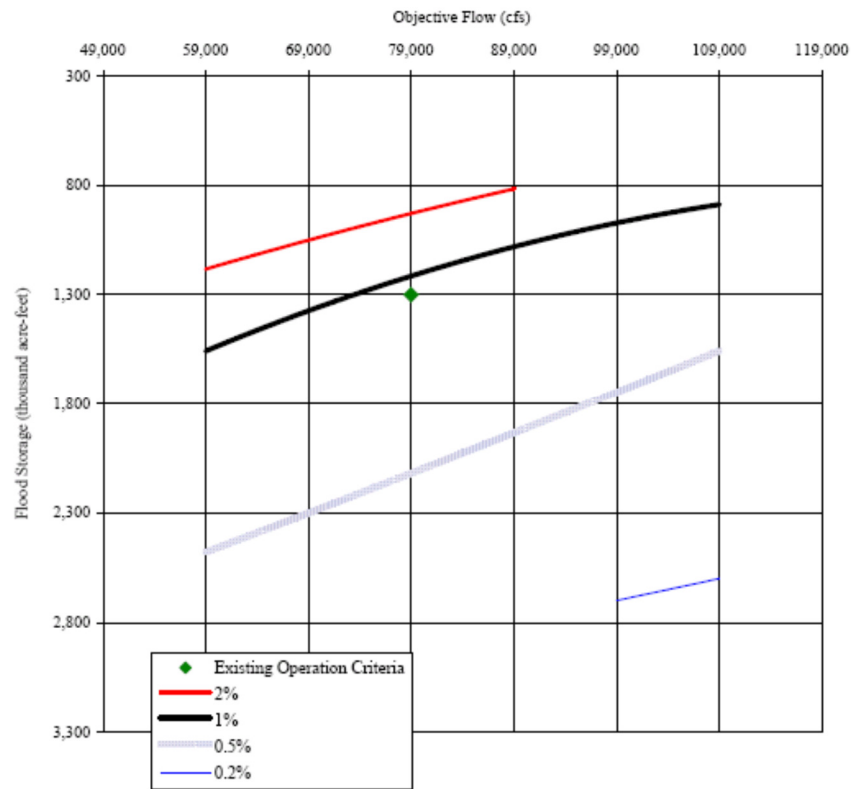
Lowering the objective release criteria could reduce reservoir outflow rates and shift the timing of the peak tributary flow to prevent coinciding with the peak flow in the mainstem. However, reducing the objective release could speed up filling of the flood pool storage and lead to earlier emergency spillway releases.

Other changes were made in the HEC-5 model for consistency between the simulations. These changes included, but were not limited to, the following:

- Starting storage of the targeted reservoir
- Gate operations
- Release ramping schedule

Figure 3-3 shows an example of grid analysis results for Shasta Lake. The curves delineate combinations of flood storage and objective flows that would pass a specified frequency event while exhausting the capabilities of the reservoir. Points above a curve indicate objective flows have been exceeded, and values below a curve indicate objective flows have not been exceeded for a particular storm event. For example, Shasta Lake is currently capable of controlling a flood event with less than a 1 percent AEP (1 percent chance of occurring in any year). Increasing the flood storage at Shasta Lake to approximately 2,100 thousand acre-feet (TAF) could enable Shasta Lake to manage up to a 0.5 percent AEP flood event without exceeding the current objective release of 79,000 cubic feet per second (cfs).

This Comprehensive Study analysis shows how changes to a reservoir's objective flow and flood storage allocation influence the level of flood protection along the mainstems and tributaries of both the Sacramento and San Joaquin rivers. Results from the grid analysis were used as a guide for the reservoir alternatives discussed below.



Source: USACE, 2002b

Notes:

1. Data representing the 50 percent and 10 percent AEP storm events are not plotted because Shasta Lake is capable of completely detaining inflows generated by events of these magnitudes.
2. Current objective flow = 79,000 cubic feet per second
3. Current maximum flood storage allocation = 1,300 thousand acre-feet

**Figure 3-3. Grid Analysis Results for Shasta Lake**

### 3.2.3 Operational Criteria Changes to Lower Basin Reservoirs

In the Comprehensive Study, the primary purpose of modifying operational criteria at lower basin reservoirs was to alter peak flows of both the mainstems and tributaries of the Sacramento and San Joaquin rivers. Alternatives included arbitrary changes in objective flow and available flood storage allocation for one or more reservoirs under different storm events. In the Sacramento River Basin, operational criteria changes were made in flood reservation and objective release to Shasta Lake, Lake Oroville, and New Bullards Bar Reservoir, and flows were limited at Cottonwood Creek (Table 3-1). In the San Joaquin River Basin, operational criteria changes were made in flood reservation and objective release at Millerton Lake (Friant Dam), Lake McClure (New Exchequer Dam), and New Don Pedro Reservoir (Table 3-2). For these alternatives, increases in flood reservation were drastic, often doubling the existing

**Table 3-1. Lower Basin Reservoir Operational Criteria Changes – Sacramento River Basin Alternatives**

Reservoir	Operational Criteria	Existing Condition	Alternative 1	Alternative 2	Alternative 3	Alternative 4
Shasta Lake	Flood Reservation	1,300 TAF	+1,300 TAF	-	-	-
	Objective Release	79,000 cfs	-	-	-	-
Cottonwood Creek	Flood Reservation	N/A	-	-	-	-
	Objective Release	N/A	-	Up to 15,000 cfs	-	-
Lake Oroville	Flood Reservation	750 TAF	+750 TAF	-	Incremental changes made to available storage and objective flow	Incremental changes made to available storage and objective flow
	Objective Release	150,000 cfs	-	-		
New Bullards Bar Reservoir	Flood Reservation	170 TAF	-	-	Incremental changes made to available storage and objective flow	-
	Objective Release	50,000 cfs	-	-		-

Source: Adapted from USACE, 2002d

Key:

- = no change

cfs = cubic feet per second

N/A = not applicable

TAF = thousand acre-feet

flood reservation. Note that doubling the flood storage for some reservoirs is a small portion of the total reservoir (e.g., adding 1,300 TAF of flood storage as compared to the total Shasta Lake storage of 4,552 TAF).

Table 3-3 contains example HEC-5 results from reservoir operational criteria changes. It presents peak flow reduction at six locations for an Ord Ferry-centered storm and seven return frequencies for Sacramento River Basin Alternative 1 (doubling flood reservation in both Shasta Lake and Lake Oroville).

Results from the Comprehensive Study alternatives demonstrated that operational criteria changes to existing reservoirs have the potential to reduce peak flow at various locations in the Sacramento and San Joaquin river basins.

**Table 3-2. Lower Basin Reservoir Operational Criteria Changes – San Joaquin River Basin Alternatives**

Reservoir	Operational Change	Existing Condition	Alt. 1	Alt. 2	Alt. 3	Alt. 4	Alt. 5	Alt. 6	Alt. 7
Millerton Lake	Flood Reservation	170 TAF	+170 TAF	+100 TAF	-	+50 TAF	+100 TAF	-	-
	Objective Release	6,500 cfs	-	-	-	Up to 4,000 cfs	-	Up to 8,000 cfs	-
Lake McClure	Flood Reservation	350 TAF	-	+50 TAF	-	-	+50 TAF	-	-
	Objective Release	6,000 cfs	-	-	-	Up to 1,000 cfs	-	-	Up to 2,000 cfs
New Don Pedro Reservoir	Flood Reservation	340 TAF	+340 TAF	+100 TAF	-	-	+200 TAF	-	-
	Objective Release	9,000 cfs	-	Up to 2,000 cfs	Up to 6,000 cfs	Up to 6,000 cfs	-	-	-

Source: Adapted from USACE, 2002d

Key:

- = no change

Alt. = Alternative

cfs = cubic feet per second

TAF = thousand acre-feet

**Table 3-3. Percent Peak Flow Reduction at Mainstem Gage Locations in Sacramento River Basin for Alternative 1**

Ord Ferry Storm Runoff Centering						
AEP (percent)	Bend Bridge	Vina Bridge	Ord Ferry	Oroville	Verona	Sacramento
50	0.0	0.0	0.0	42.7	9.6	12.2
10	0.0	0.0	0.0	36.1	8.5	6.4
4	0.0	0.0	0.0	55.0	16.8	13.3
2	0.0	0.0	0.0	53.6	15.7	12.4
1	0.0	0.0	0.0	60.9	21.2	17.0
0.5	10.2	0.0	0.0	30.0	8.4	6.9
0.2	38.6	18.7	20.0	0.0	0.8	0.5

Adapted from USACE, 2002d

Notes:

1. Flow at mainstem points are estimated by HEC-5, which assumes all flows remain in channel (bypasses were treated as channels).

2. Percent Peak Flow Reduction = ((Maximum Regulated No Project Inflow)-(Maximum Regulated Alternative Inflow))/ (Maximum Regulated No Project Inflow) X 100%.

Key:

AEP = annual exceedence probability

### **3.2.4 Major Comprehensive Study Findings**

The Comprehensive Study evaluation of potential reservoir operational criteria changes led to several important findings for flood management in the Central Valley that were used to inform operational criteria changes in the 2012 CVFPP Reservoir Analysis:

- The Central Valley flood management systems' design does not provide a uniform level of flood protection to all areas.
- The Central Valley flood management systems cannot safely convey the flows that it was formerly considered capable of accommodating.
- All of the preliminary systemwide evaluations indicated that some amount of new flood storage is needed in the Sacramento River Basin, regardless of the type of flood management improvements implemented.
- Weirs and bypasses in the Sacramento River Basin tend to dampen the effects of changes to the flood management systems.
- Under existing conditions, flow out of the Tuolumne River system overwhelms flow in the San Joaquin River downstream from the Tuolumne River confluence.
- During floods, water leaves the Central Valley foothills and moves through the different rivers and channels in the Central Valley at different rates. Thus, flood peak from one tributary might reach the mainstem hours or days before the peak from another tributary.
- If levee reliability were improved systemwide, substantial increases in flood storage capacity could offset hydraulic impacts in downstream areas because of improved upstream reliability.
- A comprehensive solution to improve public safety, reduce flood damages, and restore degraded ecosystems in the Central Valley will require a combination of measures that increase conveyance capacity and flood storage, and improve floodplain management.

### 3.3 2012 CVFPP Reservoir Analysis Assumptions

Using the preliminary findings and methodology from the Comprehensive Study, reservoir operational criteria changes were considered for the 2012 CVFPP Reservoir Analysis if a reservoir met the following conditions:

- Reservoir is multipurpose (i.e., flood management, water supply, recreation)
- Gross pool is greater than 100 TAF
- Reservoir is located within the analysis area
  - Reservoir is located within the Sacramento and San Joaquin river basins
  - Reservoir is located on mainstem or tributaries that connect directly to the mainstem
  - Reservoir is not located on eastside tributaries or within the Delta

Operational criteria at reservoirs that are solely or mostly operated for flood management (i.e., less than 100 TAF of storage is dedicated for nonflood management purposes) were not changed because insufficient flexibility existed in operations since nearly all of the storage is already dedicated to flood management. Similarly, if a reservoir had a gross pool smaller than 100 TAF, it was not considered because there is little flexibility in operations. Reservoirs located outside the Sacramento and San Joaquin river basins were not considered (i.e., Pine Flat Lake, located on the Kings River) because they are outside the area of analysis. Reservoirs located on tributaries that do not enter the Sacramento or San Joaquin rivers directly were also not included because most of the effects of operational criteria changes would not affect the mainstems. For example, Indian Valley Reservoir, on the North Fork Cache Creek, was not analyzed because Cache Creek drains into the Yolo Bypass, not directly to the Sacramento River. Reservoirs on the eastside tributaries (Cosumnes, Mokelumne, and Calaveras rivers and Littlejohns Creek), which drain into the San Joaquin River within the Delta boundary, were also not included because they are at the downstream end of the system, thus having less potential for systemwide benefits.

Of the 24 lower basin reservoirs included in the existing HEC-5 models (refer to Section 3.5.1), 9 fit these conditions; therefore, operational criteria changes at these reservoirs were explored further in this analysis (Table 3-4).



**Table 3-4. Reservoirs Considered for Operational Criteria Changes**

<b>Sacramento River Basin</b>	<b>San Joaquin River Basin</b>
Shasta Lake	New Melones Reservoir
Lake Oroville	New Don Pedro Reservoir
New Bullards Bar Reservoir	Lake McClure
Folsom Lake	H.V. Eastman Lake
	Millerton Lake

The following decisions were made for tool and methodology selection:

- Because the 2012 CVFPP Reservoir Analysis was based on the Comprehensive Study, which primarily focused on the Sacramento and San Joaquin river basins, effects on the Delta were not directly explored.
- The 2012 CVFPP Reservoir Analysis used the best available existing tools for the analysis. New reservoir simulation models (e.g., DWR and USACE HEC-ResSim models) and new hydrologic information are under development, but they were not available for this analysis.
- Operational criteria changes were made to maximize systemwide flood management benefits.
- Other effects, including water resources benefits, and hydropower and environmental impacts, were not considered when making operational criteria changes.
- No climate change or environmental analyses were conducted.

### **3.4 2012 CVFPP Reservoir Analysis Model Selection**

Three computer models were used to conduct this analysis: HEC-5, HEC-ResSim, and UNET. As described above, the 2012 CVFPP Reservoir Analysis was divided into five different activities. The first activity, review of past reservoir analyses modeling, did not require any additional modeling as part of the 2012 CVFPP. The corresponding models used for each of the remaining four activities of the analysis are as follows:

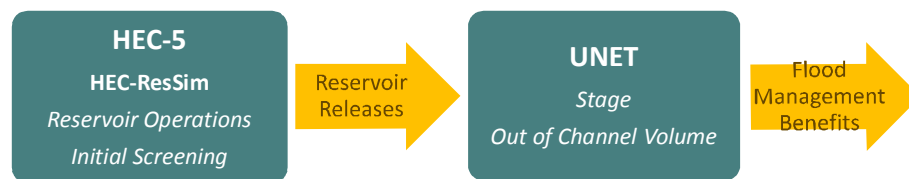
Activity 2. No Project System Performance – HEC-5 and HEC-ResSim

Activity 3. Basin-Wide Sensitivity to Reservoir Operational Criteria Changes – HEC 5

Activity 4. Reservoir Operational Scenarios Considered – HEC-5

Activity 5. Effects of Operational Criteria Changes on Flood Risk Management – UNET

Figure 3-4 shows an overview of how the models relate to each other and their inputs and outputs.



**Figure 3-4. Models Process Overview**

### 3.4.1 HEC-5 Hydrologic Reservoir Operations Model

Preliminary flood management benefits were compared using the hydrologic reservoir operations model HEC-5. This is a reservoir operations model that simulates rule curves and other operational criteria based on reservoir inflow. HEC-5 provided preliminary estimates for the reduction in peak flow, duration, and magnitude of channel capacity exceedence, and contribution of reservoir flood releases to downstream flow at index point locations (i.e., key locations of interest to observe effects of operational criteria changes) for a wide range of scenarios.

The HEC-5 model implementation developed for the Comprehensive Study and simulating all of the major reservoirs in the Sacramento and San Joaquin river basins was selected for use in this analysis because it is currently the best available systemwide model. While new tools are being developed, they were not available for use in this analysis.

The HEC-5 Comprehensive Study models represent Year 2000 reservoir operational criteria within the current flood management systems of the Sacramento and San Joaquin river basins. These models were updated for the 2012 CVFPP Reservoir Analysis to include changes to reservoir operations since completion of the Comprehensive Study (see Section 3.5.1).

### 3.4.1 HEC-ResSim Hydrologic Reservoir Operations Model

HEC-ResSim supplemented HEC-5 to simulate current reservoir operations and screen various reservoir operational criteria changes. HEC-5 is a

legacy program; HEC-ResSim, developed by USACE, is its successor and includes a graphical user interface and the ability to better simulate some types of operational rules.

HEC-ResSim was used to simulate American River and Folsom Lake operational criteria, including the new Folsom Dam JFP modifications, because it would be difficult to simulate these operations in HEC-5. While the preferred method for incorporating Folsom Dam JFP changes would be to modify HEC-5, doing so would not accurately reflect the Folsom Dam JFP. HEC-5 was unable to accurately simulate the variable release diagram and design targets associated with the Folsom Dam JFP. As a result, the USACE HEC ResSim model of the American River was used to simulate releases from Folsom Lake. Results from the HEC-ResSim model were used as input into the HEC-5 model.

Although HEC-ResSim demonstrates more advanced features and improvements than HEC-5, it was only used to simulate reservoir operations in the American River Basin because systemwide HEC-ResSim models were not available at the time of this analysis.

### 3.4.1 UNET Hydraulic Model

Once the two potential scenarios for consideration were identified, UNET was run to assess in more detail the effects of operational criteria changes on flood management. UNET used the time series of reservoir releases from HEC-5 to compute the stage and out-of-channel volume of water throughout both basins. UNET is an unsteady-state riverine hydraulic flow model that simulates the one-dimensional (1-D) flow in a network of streams. The UNET model used in this analysis was first developed as part of the Comprehensive Study to simulate floods in the Sacramento and San Joaquin river basins, including levee breaks.

New river hydraulic models are currently under development by DWR, but were not available for the 2012 CVFPP. Therefore, the available UNET model and data, with some updated information, were used for analyses required for the CVFPP.

### 3.5 2012 CVFPP Reservoir Analysis Model Specifications

The following describes model specifications for the three models used in this analysis. Because the majority of the 2012 CVFPP Reservoir Analysis used HEC-5 to explore operational criteria changes, additional detail is provided regarding the HEC-5 model, its model limitations, and available storm event inputs.

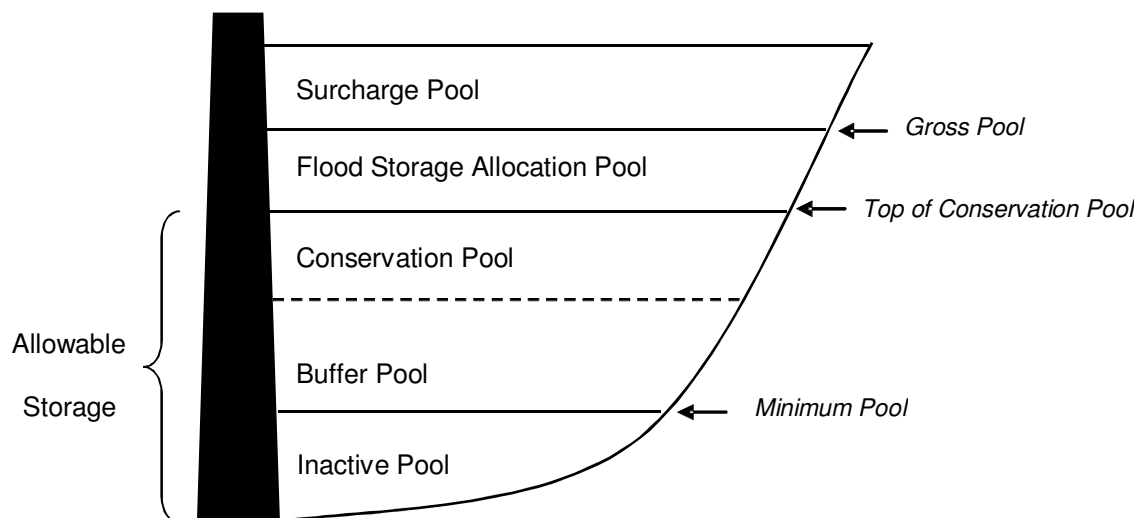
#### 3.5.1 HEC-5 Model Specifications

HEC-5, a computer program first developed and distributed in 1973, was designed by USACE HEC to offer guidance in real-time reservoir release decisions and to aid in planning studies for proposed reservoirs, operation alternatives, and flood space allocation based on specified project demands and constraints. HEC-5 can simulate a dendritic reservoir system configuration of streams, weirs, bypasses, and storage areas. The program accepts criteria related to flood operations, hydropower generation, river routings, diversions, and low-flow operations. Simulations can be performed using time steps ranging from 5 minutes to 1 month.

With support from the USACE Water Management Section of the Sacramento District, HEC constructed working HEC-5 models for flood damage reduction reservoirs within the Central Valley. The Water Management Section began detailed modeling in 1999 to expand the working models into calibrated models capable of performing reservoir simulations for an entire watershed under hydrologic conditions of differing return frequencies and storm centerings.

HEC-5 routes flow through reservoirs based on operational criteria provided by the modeler. Operational criteria in the No Project HEC-5 models strictly observe guidelines established within each reservoir's water control manual and focus on flood damage reduction operations, as well as winter operations for water supply and hydropower. Figure 3-5 shows the basic operational zones of a reservoir in HEC-5.

Under normal conditions, when reservoir storage begins to encroach into the flood storage allocation pool (i.e., storage exceeds the top of conservation pool), reservoir outflow is ramped up to match the inflow, but not to exceed the objective release to evacuate water from the flood storage allocation pool. The objective release is based on downstream channel capacity and reservoir outlet capacity. If inflow into a reservoir is greater than outflow, the volume of water in the reservoir continues to increase, and emergency spillway releases (which are greater than objective releases) begin when storage reaches the gross pool.



*Adapted from Hickey et al., 2003*

Inactive Pool – Storage in this pool may be zero or a minimum pool.

Buffer Pool – This is part of the conservation pool; when the water level drops into the buffer pool, only essential demands will be met.

Conservation Pool – Space is reserved for various water demands on the reservoir (e.g., agricultural, municipal).

Flood Storage Allocation Pool – Water is stored in this pool when it cannot be safely passed downstream within objective flow targets.

Surchage Pool – Water in this pool is above the emergency spillway; outflows are determined by the spillway capacity or Emergency Spillway Release Diagram.

**Figure 3-5. Basic Operational Zones of a Reservoir in HEC-5**

Four separate HEC-5 models were used for the 2012 CVFPP Reservoir Analysis: two for the Sacramento River system and two for the San Joaquin River system. Each system has one model that represents the headwater reservoirs and a second model for the lower basin flood management facilities. The headwater model for each basin generally contains reservoirs located upstream from flood damage reduction projects. Lower basin models contain flood reduction projects as well as water supply, recreation, and hydropower facilities. Reservoirs simulated in the HEC-5 models either currently have flood damage reduction functions or maintain an active storage of greater than 10,000 acre-feet and regulate a significant natural drainage area. The operations of lower basin reservoirs are based on their respective water control manuals. Water control manuals are prepared by USACE for each reservoir that has variable allocations for flood control during the year. Water control manuals also specify reservoir inflow parameters, and contain notes prescribing the use of storage space in terms of release schedules, runoff, nondamaging or other controlling flow rates downstream from the damsite, and other major factors as appropriate.

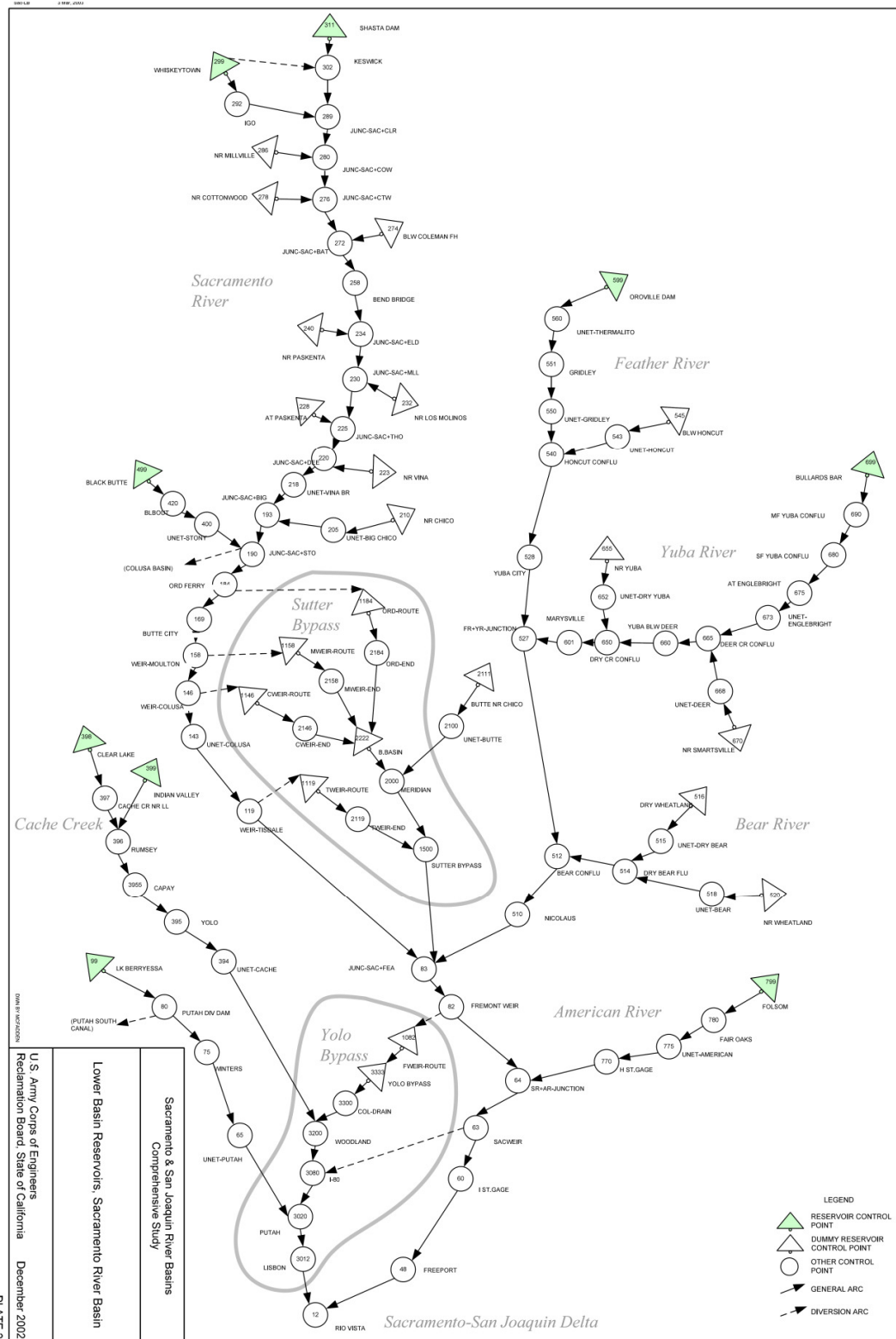
These models can be run for various storm centerings. As described above, 1 storm centering for each basin was used for the 2012 CVFPP Reservoir Analysis. Storm centerings are defined according to the location in the

basin where the highest intensity floodflows occur, although a storm may occur throughout the basin. The process used to analyze each storm centering is described in Attachment 8A: Hydrology. An overview of the storm centerings is provided later in this section.

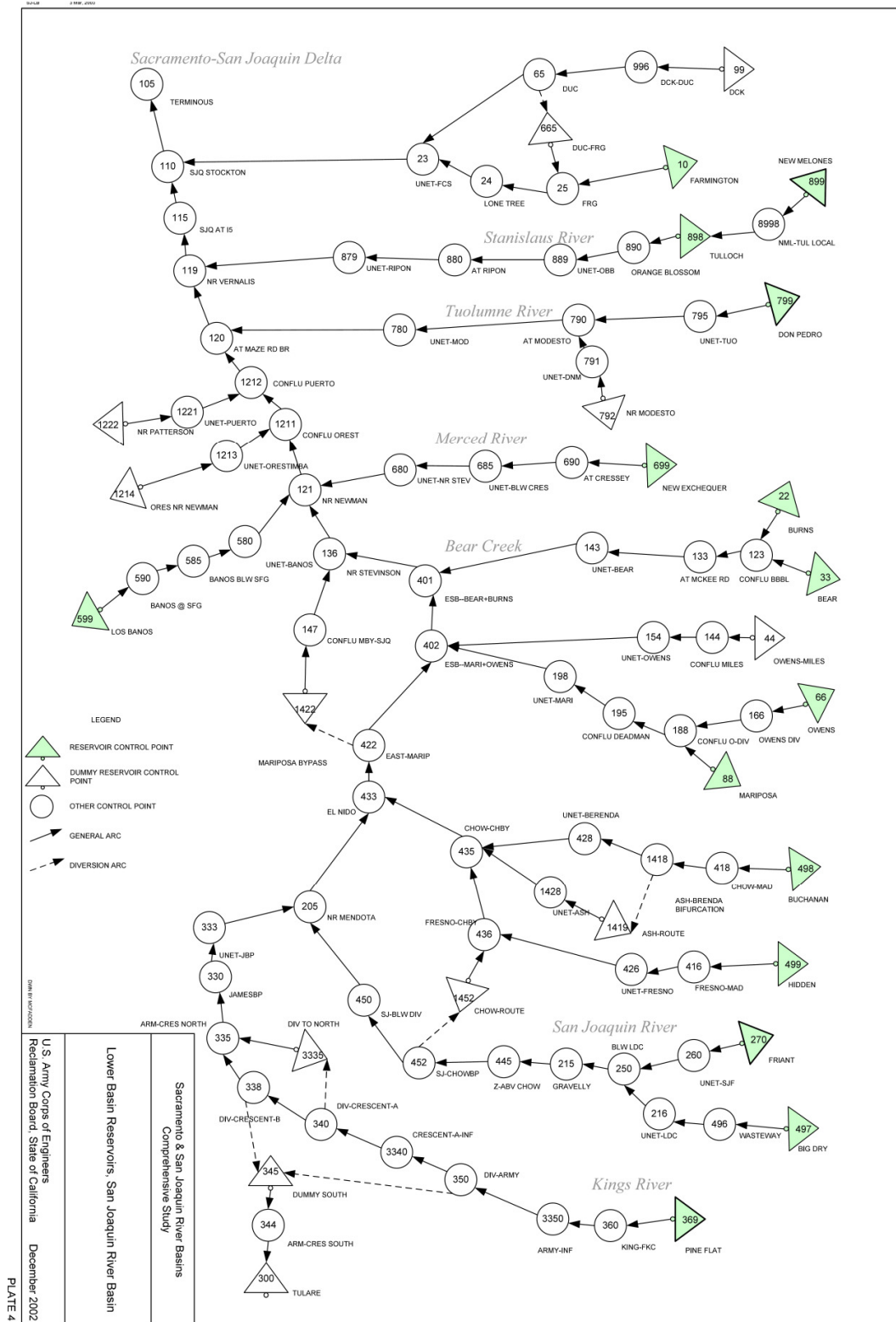
In the lower basin models, HEC-5 applies Muskingum routing (hydrologic routing) to simulate river routing that delays and attenuates flows as water travels downstream from a reservoir through river reaches. Travel times and attenuation factors were determined through past studies, comparison with historical flood hydrographs, communication with local water agencies, and channel characteristics. The routing coefficients were assumed to be the same for all storm AEPs.

Figures 3-6 and 3-7 are HEC-5 lower basin model schematics for the Sacramento and San Joaquin river basins, respectively. The triangle symbols represent reservoirs and riverine control points; circles represent other control points.

HEC-5 requires a reservoir to be located at the most upstream location in a subreach; hence, riverine control points are represented as pseudo reservoirs (also known as dummy reservoirs). Pseudo reservoirs do not model physical reservoirs, nor do they have any storage. They are a modeling artifact for locations that receive diverted flows; flows simply pass through these locations without any regulation. Table 3-5 lists reservoirs, as well as important notes and assumptions, simulated in the HEC-5 lower basin model for the Sacramento River Basin. Table 3-5 also shows a similar list for the San Joaquin River Basin.



# 2012 Central Valley Flood Protection Plan Attachment 8B: Reservoir Analysis



Source: USACE, 2002b

**Figure 3-7. HEC-5 Schematic for San Joaquin River Basin**



### ***HEC-5 Model Limitations***

The HEC-5 models represent Year 2000 reservoir operational criteria within the current flood management systems of the Sacramento and San Joaquin river basins. HEC-5 simulates the regulated flow time series for hydraulic models (UNET) to perform detailed downstream hydraulic routing. These models, developed for the Comprehensive Study, were updated as necessary for the 2012 CVFPP Reservoir Analysis.

The hydrologic routing of HEC-5 allows modeling of floodflow conditions along the river mainstem below the reservoirs. More detailed hydraulic models are required to predict site-specific flow conditions. UNET models are the appropriate hydraulic tools to predict flow rates and water stages at various riverine locations inside the Sacramento and San Joaquin river basins. However, the HEC-5 models provide reconnaissance-level flow evaluation of river mainstems for prefeasibility studies.

These HEC-5 models have the following key assumptions and limitations:

- Models were developed for use only with synthetic hourly hydrographs from January 1 through February 4. To simulate other time steps or series, adjustments may need to be made.
- FEMA requires that the starting storage of any headwater reservoir be established as that reservoir's gross pool for floodplain studies. However, the Comprehensive Study simulations established starting storages of the headwater reservoirs as an average of their storages during the 1997, 1995, and 1986 Central Valley storm events. If the average storage thus computed was greater than gross pool, gross pool was used as the starting storage.
- For the lower basin reservoirs, the starting storage was at the top of conservation pool. This assumes a maximum basin wetness and thus, the required maximum available flood space.

**Table 3-5. HEC-5 Lower Basin Reservoirs in Sacramento and San Joaquin River Basins**

Reservoir	River	Owner	Objective Flow	Gross Pool Storage (TAF)	Maximum Flood Space (TAF)	Notes
<b>Sacramento River Basin</b>						
Shasta Dam and Lake	Sacramento River	Reclamation	Below dam – 79,000 cfs Bend Bridge – 100,000 cfs	4,552	1,300	
Whiskeytown Dam and Lake	Clear Creek	Reclamation	N/A	241	N/A	No formalized flood space
Black Butte Dam and Lake	Stony Creek	USACE	Below dam – 15,000 cfs	144	136	Up to 40 TAF of storage can be transferred based on storage in East Park and Stony Gorge
Oroville Dam and Lake Oroville	Feather River	DWR	Below dam – 150,000 cfs Gridley – 150,000 cfs Yuba City – 180,000 cfs Feather-Yuba River Junction – 300,000 cfs Nicolaus – 320,000 cfs	3,538	750	
New Bullards Bar Dam and Reservoir	Yuba River	YCWA	Below dam – 50,000 cfs Marysville at Yuba River – 180,000 cfs	970	170	
Folsom Dam and Lake	American River	Reclamation	Below dam – 115,000 cfs	975	670	Up to 200 TAF of storage can be transferred based on storage in French Meadows, Hell Hole, and Union Valley
Clear Lake and Cache Creek Dam	Cache Creek (South Fork)	YCFC&WCD	N/A	314	150	No formalized flood space, but YCFC&WCD holds appropriative rights for up to 150 TAF per year.
Indian Valley Dam and Reservoir	Cache Creek (North Fork)	YCFC&WCD	Below dam – 10,000 cfs Rumsey – 20,000 cfs	301	40	
Monticello Dam and Lake Berryessa	Putah Creek	Reclamation	Below dam – 16,000 cfs	1,564	N/A	No formalized flood space

**Table 3-5. HEC-5 Lower Basin Reservoirs in Sacramento and San Joaquin River Basins (contd.)**

Reservoir	River	Owner	Objective Flow	Gross Pool Storage (TAF)	Maximum Flood Space (TAF)	Notes
<b>San Joaquin River Basin</b>						
Pine Flat Dam and Lake	Kings River	USACE	Kings River North – 4,750 cfs Kings River South – 3,200 cfs	1,000	475	Up to 162 TAF of storage can be transferred based on storage in Courtright and Wishon
Big Dry Creek Dam and Reservoir	Dry Creek	FMFCD	Wasteway – 700 cfs	30	30	Has been historically used for flood management, but cannot always be relied on
Friant Dam and Millerton Lake	San Joaquin River	Reclamation	Little Dry Creek – 8,000 cfs Mendota Gage – 6,500 cfs	521	170	Up to 85 TAF of storage can be transferred based on storage in Mammoth Pool
Hidden Dam and Hensley Lake	Fresno River	USACE	Fresno River at Madera Canal – 5,000 cfs	90	65	
Buchanan Dam and H.V. Eastman Lake	Chowchilla River	USACE	Below dam – 7,000 cfs Chowchilla River at Madera Canal – 7,000 cfs	151	45	
Mariposa Dam and Reservoir	Mariposa Creek	USACE	N/A	15	15	
Owens Dam and Reservoir	Owens Creek	USACE	N/A	4	4	
Bear Dam and Reservoir	Bear Creek	USACE	N/A	8	8	
Burns Dam and Reservoir	Burns Creek	USACE	N/A	7	7	
New Exchequer Dam and Lake McClure	Merced River	MID	Cressey – 6,000 cfs	1,025	350	
Los Banos Dam and Detention Reservoir	Los Banos Creek	Reclamation	Los Banos – 1,000 cfs	35	14	
New Don Pedro Dam and Reservoir	Tuolumne River	TID	Modesto (Tuolumne River below Dry Creek) – 9,000 cfs	2,030	340	
New Melones Dam and Lake	Stanislaus River	Reclamation	Orange Blossom Bridge – 8,000 cfs	2,420	450	

**Table 3-5. HEC-5 Lower Basin Reservoirs in Sacramento and San Joaquin River Basins (contd.)**

<b>Reservoir</b>	<b>River</b>	<b>Owner</b>	<b>Objective Flow</b>	<b>Gross Pool Storage (TAF)</b>	<b>Maximum Flood Space (TAF)</b>	<b>Notes</b>
Tulloch Dam and Reservoir	Stanislaus River	Oakdale, So. San Joaquin ID	Orange Blossom Bridge – 8,000 cfs	68	10	Flow-through reservoir; generally releases are the same as New Melones except in high flows
Farmington Dam and Reservoir	Littlejohns Creek	USACE	Town of Farmington – 2,000 cfs	52	52	

Key:

cfs = cubic feet per second

DWR = California Department of Water Resources

FMFCD = Fresno Metropolitan Flood Control District

ID = Irrigation District

MID = Merced Irrigation District

N/A = Not applicable, no specified objective releases or flood storage allocation

Reclamation = U.S. Department of the Interior, Bureau of Reclamation

TAF = thousand acre-feet

TID = Turlock Irrigation District

USACE = U.S. Army Corps of Engineers

YCFC&WCD = Yolo County Flood Control & Water Conservation District

- Guidelines established within each reservoir's water control manual were strictly observed.
- Some reservoirs with stepped release schedules rely on both the percentage of required flood control space used and peak inflow in determining flood releases. For these reservoirs, fixed percentages of required flood control space used were assumed.
- Muskingum routing parameters were fixed for all simulated exceedence frequencies.
- Local flows were either synthetically produced or were assumed to be a ratio of the short duration maxima of a nearby natural flow hydrograph. These ratio multipliers were not scaled for each simulated exceedence frequency. For more detailed studies, variable ratio multipliers based on floodflow frequency should be examined.
- Calibration and verification were accomplished using Central Valley flood events in 1995 and 1997 and by comparing these to manual routings published in water control manuals.
- It was assumed that all river channels have infinite capacity (i.e., all flows would be routed through the channels even if channel capacity was exceeded). No losses, such as evaporation, seepage, and overbank flow due to levee breaks, were simulated.
- HEC-5 cannot integrate concisely some of the operating criteria for some reservoirs. The multiparameter "Release Schedules" for Black Butte, Shasta, and Oroville lakes had to be written into the model by assuming one of the variable parameters to be constant. Similar difficulties with Black Butte Dam (Ord Ferry) required that an operational point be excluded from the simulations. Complications with the forecast capabilities of HEC-5 required that one of the operating points of Friant Dam be located outside the program's forecast window.
- The simulation program assumed near certainty in flow contributions from downstream tributaries when operating facilities for flows at that location or downstream from that location. Uncertainty in forecasting downstream flow contributions should be addressed in a risk analysis along with other variables affecting the operational efficiency of a reservoir.

For more information about the capabilities of the HEC-5 simulation program and its basic assumptions and limitations, refer to the October

*HEC-5 Simulation of Flood Control and Conservation Systems User's Manual* (USACE, 1998) and the December *Comprehensive Study Reservoir Simulation Models User's Guide* (USACE, 2002b).

### **Updates to Models**

Changes were made to the Comprehensive Study HEC-5 models to include the Feather-Yuba F-CO program and Folsom Dam JFP modifications. It was assumed that implementing the SJRRP had no effect on flood operational criteria at Millerton Lake.

**Feather-Yuba F-CO Program** The goal of the F-CO program is to improve flood protection for communities along and downstream from the Yuba and Feather rivers without impacting the water supply of Lake Oroville and New Bullards Bar Reservoir. This was accomplished through reducing peak floodflows via improved river flow forecasting and improved operational coordination between Lake Oroville and New Bullards Bar Reservoir (YCWA, 2008).

To incorporate these changes into the model, the following two downstream control points for which New Bullards Bar Reservoir is operated were added to the HEC-5 model (as specified in the Reservoir Operations (RO) Points record): confluence of Yuba and Feather rivers, and Feather River at Nicolaus. Adding these operational criteria points means that when channel capacity is close to being exceeded at these control points, Lake Oroville and New Bullards Bar Reservoir will modify their releases based on available flood storage space to maintain channel capacity. To meet downstream channel capacities, the reservoir with the largest percentage of allocated flood storage still available would lower its releases more than the other reservoir.

**Folsom Dam JFP** As mentioned, the Folsom Dam JFP is a collaborative effort by Reclamation and USACE to address dam safety hydrologic risk at Folsom Lake and improve flood protection. Among other modifications, this project will include a new auxiliary spillway, a change in Folsom Lake operational criteria capabilities provided by the new auxiliary spillway, improved weather forecast products, and alternative variable storage options. The following text briefly summarizes key changes to Folsom Lake operational criteria. Note that all routing assumptions documented in support of design decisions are subject to further refinement or optimization efforts via the Folsom Dam Permanent Operations (FPO) Study. For more information on the changes to Folsom Lake, refer to the *Folsom Dam Auxiliary Spillway Control Structure Draft Design Documentation Report* (USACE, 2009) and <http://www.usbr.gov/mp/jfp/> (Reclamation, 2009).

While the preferred method for incorporating Folsom Dam JFP changes would be to modify HEC-5, this did not accurately reflect the Folsom Dam JFP. HEC-5 was not capable of accurately simulating the variable release diagram and design targets associated with the Folsom Dam JFP. As a result, the HEC-ResSim model of the American River, developed by USACE, was used to simulate releases from Folsom Lake. More details on incorporating the Folsom Dam JFP into the model are provided in the following HEC-ResSim subsections.

### **Storm Events**

There were seven AEP storm events developed for the Comprehensive Study and were available to use for the 2012 CVFPP Reservoir Analysis (Table 3-6). Another way of representing AEP is to use the inverse of the percent exceedence to describe the exceedence probability of a storm or flood using a return period, which is the long-term expected return period for a given exceedence.

**Table 3-6. Comprehensive Study Simulated Frequency Events**

<b>AEP (percent)</b>	<b>Return Period</b>
50	2-year
10	10-year
4	25-year
2	50-year
1	100-year
0.5	200-year
0.2	500-year

Key:

AEP = annual exceedence probability

In the HEC-5 Sacramento River Basin model, the following storm centers were developed for the Comprehensive Study:

- Shasta Lake to Ord Ferry (Shasta centered)
- Sacramento River at latitude of Ord Ferry<sup>2</sup> (Ord Ferry centered)
- Yuba River near Marysville (Yuba centered)
- Feather River at Oroville (Oroville centered)
- Sacramento River at latitude of Sacramento (Sacramento centered)

<sup>2</sup> All "at latitude" locations represent mainstem storm runoff centerings.

- American River at Fair Oaks (American centered)

In the HEC-5 San Joaquin River Basin model, the following storm centers were developed for the Comprehensive Study:

- San Joaquin River at Friant (Friant centered)
- San Joaquin River at latitude of El Nido (El Nido centered)
- San Joaquin River at latitude of Newman (Newman centered)
- San Joaquin River at latitude of Vernalis (Vernalis centered)
- Merced River at Exchequer (Exchequer centered)
- Tuolumne River at Don Pedro (Don Pedro centered)

According to Phase 1 objectives, which were to gain a high-level understanding of the two basins and run preliminary reservoir operational criteria change simulations, the storm events applied are essentially the same as those described above, except the following:

- The 50 percent AEP events were not evaluated because it was anticipated that both the Sacramento and San Joaquin river basins can safely pass flows resulting from such frequent events.
- It was recognized that while individual tributary storm centers could generate very different flow conditions for local tributaries, from a basin-wide perspective (which is the focus of CVFPP), tributary storm centers that are relatively close together would likely result in similar peak flow conditions along the Sacramento and San Joaquin rivers. Storm centers for the Feather River at Oroville in the Sacramento River Basin and the Tuolumne River at Don Pedro in the San Joaquin River Basin were not evaluated because of the proximity of the storm centers to the Yuba River near Marysville and the Merced River at Exchequer, respectively.

For Phase 2, fewer AEPs and storm centerings were selected to efficiently analyze a wide range of operational criteria changes while gaining a better understanding of how the system would react to these specific operational criteria changes. Storm frequencies for the Phase 2 analysis were selected based on the ability of the reservoirs in the basin to manage floodflows, and of the Sacramento and San Joaquin rivers to convey flows within the channel capacity. For the Sacramento River Basin, the 1 and 0.5 percent AEP storms were chosen to compare reservoir operational criteria



scenarios. These AEPs were chosen because the channel capacity was generally not exceeded for the No Project condition in the Feather River Basin (which was the focus of Phase 2 changes) for storms that occurred more frequently than a 1 percent AEP. If channel flows were within channel capacity, it was assumed that the system can safely convey the water without flooding adjacent areas. Because flow was within channel capacity, operational criteria changes would not affect the volume of flooding. While the 0.5 percent AEP storm occurs infrequently, and any benefit derived from operational changes would be minimal when distributed over the frequency of occurrence of large floods, it was included in this analysis because reservoir operational criteria changes have the potential to noticeably lower the channel flow rate in the Sacramento River Basin for a 0.5 percent AEP storm. The 0.2 percent AEP storm was not used in the comparison because of the storm's extremely infrequent nature.

For the San Joaquin River Basin, the 2 and 1 percent AEP storms were chosen for preliminary comparisons of the reservoir operational criteria change scenarios. Because of the generally lower channel capacity of this basin, storms that occur more frequently were selected. The channel capacity was exceeded for the No Project condition in the downstream portion of the San Joaquin River for storms that occurred more frequently than a 2 percent AEP. The 0.5 and 0.2 percent AEP storms were not used in the comparison because, as seen during the Phase 1 analysis, the magnitudes of these storms were so large that reservoir operational criteria changes alone would not be sufficient to keep flows within the channel capacity of most streams in the basin.

The storm centerings used in Phase 2 to compare the No Project condition with reservoir operational criteria changes for the Sacramento and San Joaquin river basins are the Sacramento and Vernalis storm centerings, respectively. These storm centerings were selected because they resulted in the highest simulated river stages (as determined using UNET) basin-wide for a majority of the AEPs (refer to Attachment 8C: Riverine Channel Evaluations for more details regarding UNET modeling). Selecting one centering for each basin allowed the simulated effects of reservoir operational criteria changes throughout the basin to be easily compared.

### ***Locations***

In the Sacramento River Basin, observations at index points throughout the basin were used to demonstrate potential peak flow reduction from reservoir operational criteria changes (Table 3-7 and Figure 3-8).

The Sacramento River at Ord Ferry was used in Phase 1 to indicate the effects of changes to Shasta Lake operational criteria. Yuba City and

Marysville were selected because they had both previously experienced serious flooding, and river flows at these two locations are indicative of the effects of Oroville and New Bullards Bar reservoirs' operational criteria changes, respectively. The confluence of the Feather and Yuba rivers and Nicolaus were chosen to better describe the additive effect of the changes in operational criteria to Oroville and New Bullards Bar reservoirs. Changes in operation at Folsom Lake would affect the American River at the H and I Street gages. Locations on the Sacramento River downstream from the Fremont Weir and at Freeport were selected to describe the collective effects to the Sacramento River from operational criteria changes for multiple upstream reservoirs.

**Table 3-7. Sacramento River Index Point Locations for HEC-5 Analysis**

Index Point	Phase 1	Phase 2
Sacramento River Downstream from Ord Ferry	X	N/A
Feather River at Yuba City	X	N/A
Yuba River at Marysville	X	N/A
Confluence of Feather and Yuba Rivers	X	X
Feather River at Nicolaus	X	X
Sacramento River Downstream from Fremont Weir	X	N/A
Confluence of Sacramento and Feather Rivers	N/A	X
Sacramento River at I Street Gage	N/A	X
Sacramento River at H Street Gage	X	N/A
At Lake Oroville	N/A	X
Sacramento River at Freeport	X	N/A

Key:  
N/A = not applicable

Phase 2 mainly focused on flow at the confluence of the Feather and Yuba rivers to observe the preliminary effects of reservoir operational criteria changes. Flow at the confluence of the Feather and Yuba rivers is the farthest upstream location influenced by coordinated operations of both Lake Oroville and New Bullards Bar Reservoir, the two reservoirs analyzed in this phase. Once the scenarios for further consideration were identified, flow effects at four additional index point locations were observed (Table 3-7).

In the San Joaquin River Basin, observations at index points throughout the basin were used to demonstrate potential peak flow reduction from reservoir operational criteria changes (Table 3-8 and Figure 3-9).

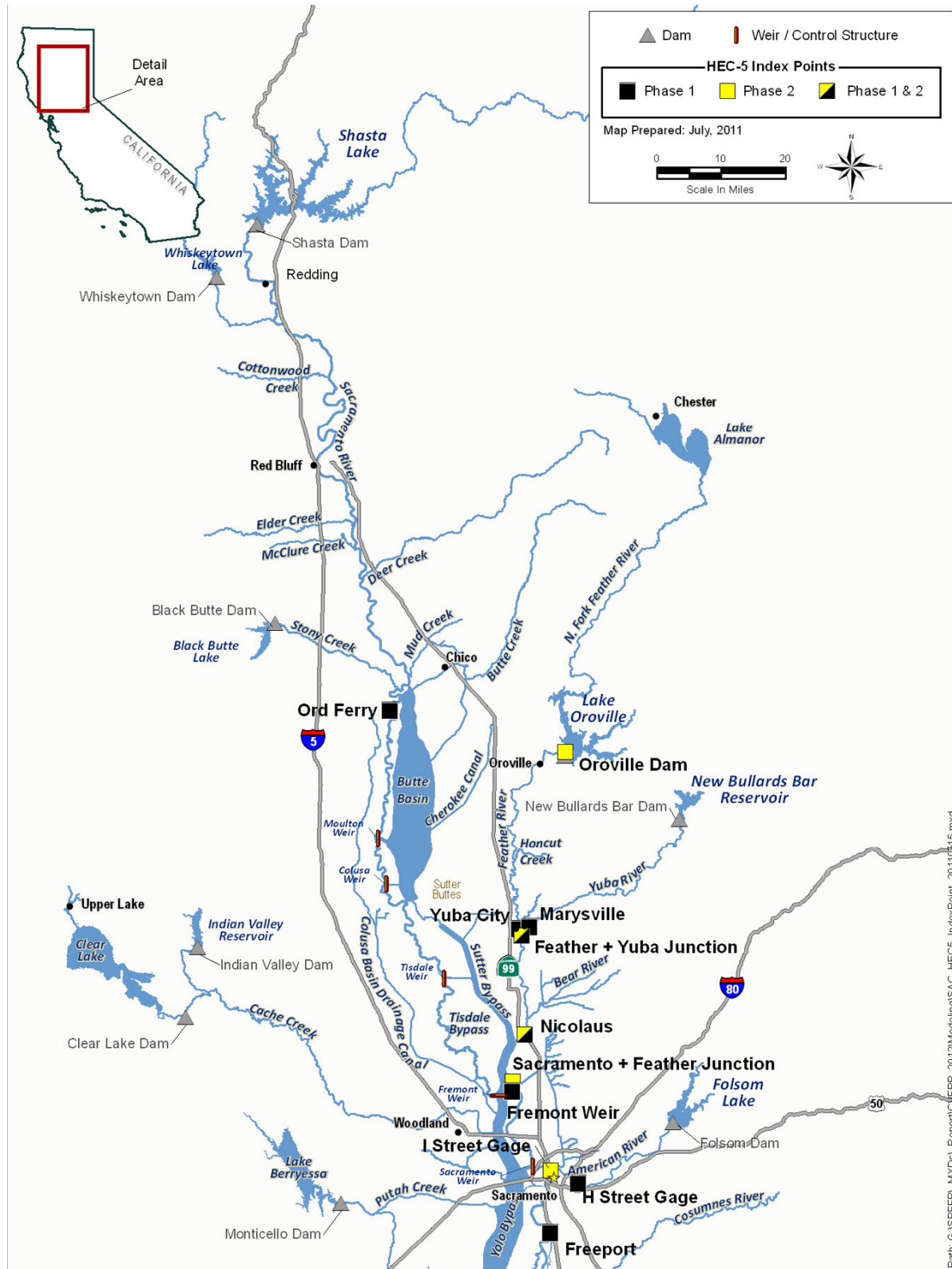


Figure 3-8. Sacramento River Basin HEC-5 Index Point Locations

**Table 3-8. San Joaquin River Index Point Locations for HEC-5 Analysis**

Index Point	Phase 1	Phase 2
Near Mendota	X	N/A
Chowchilla Bypass near Fresno River	N/A	X
El Nido	X	X
Near Newman	X	X
At Maze Road Bridge	N/A	X
Near Vernalis	X	X
Stockton	X	X

Key:  
N/A = not applicable

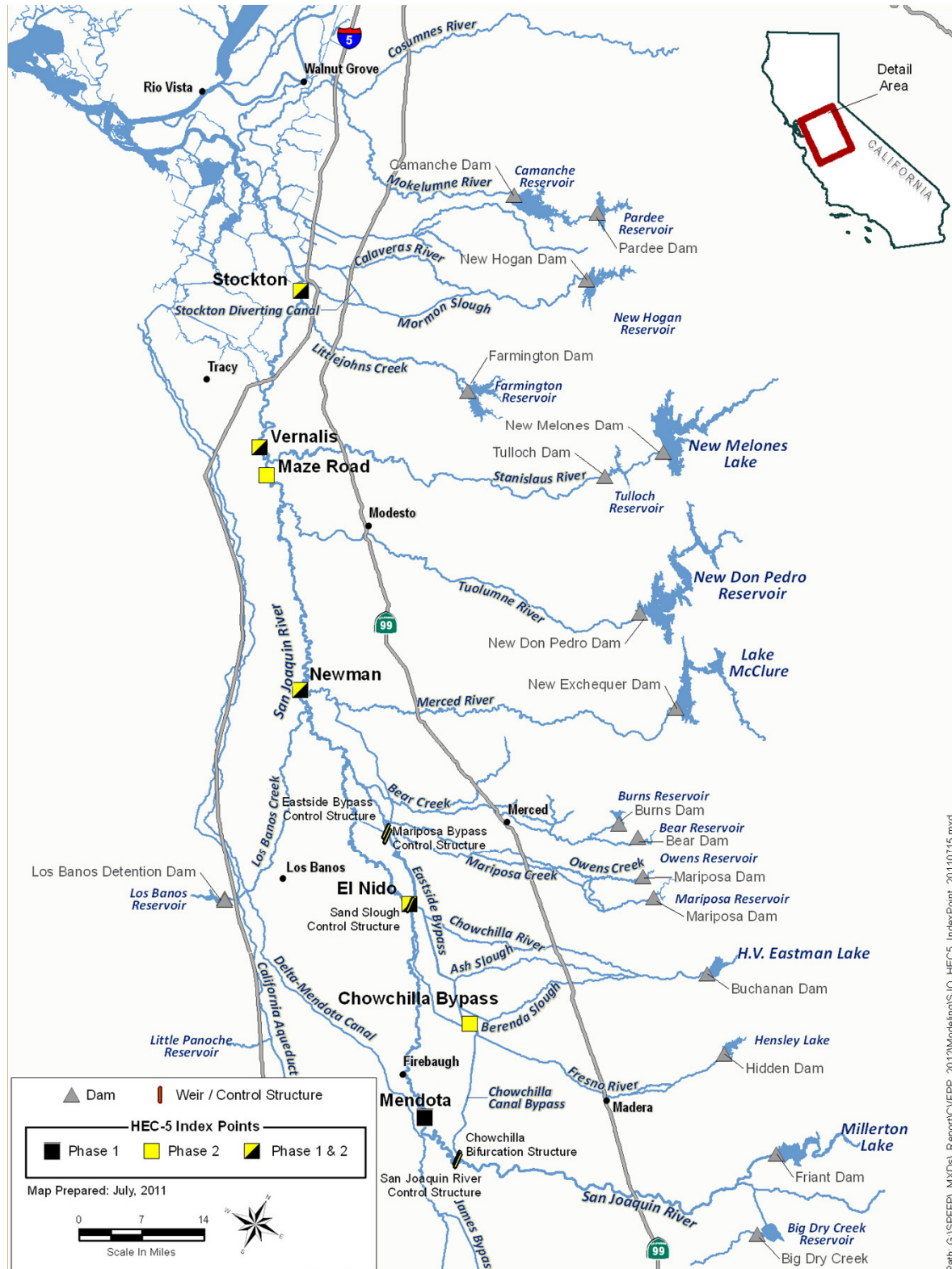
The index point near Mendota was selected because it is downstream from Millerton Lake. For Phase 2, the Chowchilla Bypass near the Fresno River was selected because most of the floodflows would be routed through the Chowchilla Bypass. El Nido, near Newman, at Maze Road Bridge, and near Vernalis are located on the mainstem of the San Joaquin River and were chosen because they are located downstream from the confluences of tributaries with major multipurpose reservoirs. Stockton was selected because it is the most downstream location in the HEC-5 model and would show the collective effects of multiple reservoir operational criteria changes.

Similar to the Sacramento River Basin, Phase 2 mainly focused on flow at one location in the San Joaquin River Basin, at Stockton, to observe the preliminary effects of reservoir operational criteria changes. Once the scenarios for further consideration were identified, flow effects at five additional index point locations were observed (Table 3-8).

### ***Operational Criteria Changes***

Changes in reservoir operational criteria were incorporated into HEC-5 for multipurpose reservoirs within the Central Valley. Similar to the Comprehensive Study, this 2012 CVFPP Reservoir Analysis assumed that the most likely operational criteria changes would be as follows:

- Changes to the flood management rule curves (i.e., increasing the amount of space dedicated to flood storage)
- Changes to the objective flow to which the reservoir is operated



**Figure 3-9. San Joaquin River Basin HEC-5 Index Point Locations**

The flood management rule curve used in HEC-5 was modified through increasing the amount of required flood space in a reservoir by lowering the parameters in the model that represent the top of conservation pool (see Figure 3-5 for a simple flood rule curve). While increasing the required flood space could also be achieved through physical changes, no modifications to the total reservoir capacity or appurtenances were made for this analysis, but some reservoirs required modification of spillway operation parameters in HEC-5 for operational criteria consistent with the new flood storage level.<sup>3</sup>

For each scenario, it was assumed that the starting storage for all lower basin reservoirs was at the top of conservation pool; hence, increasing the available flood storage decreased the starting storage for each reservoir.

Decreasing the objective release in the HEC-5 models would lower the magnitude of flows being released from a reservoir until reservoir storage reached gross pool and emergency spillway operations began. Objective releases were decreased by lowering the maximum flow limit at downstream operating points and downstream channel capacities based on reservoir level. Reservoir diversions and gate regulations associated with flow rates were also modified, when applicable.

### ***Systemwide Peak Flow Reduction***

As described, HEC-5 was used to observe the effect of changes to reservoir operational criteria on peak flow at key index point locations throughout the basins. The peak flows are not the exact flows that would occur in an actual flood because the channel routing in HEC-5 simulates attenuation and travel time, but not losses from the channel. As a result, levee breaks are not included in the model, but for downstream locations and large storm events, it is possible, or even likely in some cases, that levee breaks would have occurred upstream, thereby reducing flows in the downstream reaches of the river. This analysis focuses on the relative change in downstream peak flows resulting from scenarios that simulated changes in reservoir operational criteria, and not absolute simulated peak flows.

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<sup>3</sup> Scenarios that lower the top of conservation pool become 50 percent encroached at a lower volume, causing emergency spillway operations to begin at an earlier time. For example, if the original top of conservation pool is at 100 TAF and the gross pool is at 200 TAF, the reservoir is 50 percent encroached when the volume is 150 TAF. If the top of conservation pool is lowered by 50 TAF, emergency spillway operations would begin at 125 TAF (50 percent encroached). Instead of gate operations being related to the percentage encroached, this analysis assumed that emergency spillway operations began at the same volume as for the No Project condition. As a result, for this example, the HEC-5 data file was modified such that emergency spillway operations occurred at 150 TAF in both cases (i.e., at 67 percent encroached in the scenario).

The timing, magnitude, and duration of flow into rivers and tributaries varies, depending on the storm centering and AEP; hence, one operational criteria change would not always have the same effect at every index point location. As a result, for each basin, Phase 2 focused on only one storm centering (Sacramento storm centering for the Sacramento River Basin and Vernalis storm centering for the San Joaquin River Basin) and two AEPs during the basin-wide sensitivity analysis to better compare the effects of operational criteria changes.

### 3.5.2 HEC-ResSim Model Specifications

USACE has been developing new HEC-ResSim models as part of the DWR and USACE Central Valley Hydrology Study. USACE has completed the calibration of the new HEC-ResSim models for the Sacramento and San Joaquin river basins using HEC-5 Comprehensive Study hydrology. These HEC-ResSim models are currently undergoing quality assurance and quality control; the models have not yet been released to the public (USACE, 2010).

As described above, HEC-ResSim was used to supplement the HEC-5 model because the HEC 5 model (developed during the Comprehensive Study) does not include the Folsom Dam JFP modifications. To simulate Folsom Dam JFP operational criteria effects on Folsom Lake, the following changes to Folsom Lake operational criteria were incorporated into HEC-ResSim: (1) updated model inputs (i.e., spillway ratings and capacity curve), (2) modified flood space requirements, (3) updated Emergency Spillway Release Diagram (ESRD), and (4) changed operational criteria to reflect new design targets.

The updated model inputs include 1997 outlet ratings and new auxiliary spillway with a capacity of 138,519 cfs at elevation 418 feet. Flood space requirements were modified in accordance with the new water control diagram for Folsom Lake. This will reduce the variable flood storage allocation from the current operating range of 400 TAF to 670 TAF to 400 TAF to 600 TAF once improvements to Folsom Dam are completed (according to the federal Water Resources Development Act of 1999). Also, emergency spillway operations were modified to reflect the updated ESRD. Operational criteria for Folsom Dam and Lake were changed to reflect new design targets. These targets included limiting the discharge for the 1 percent AEP storm event to 115,000 cfs, and discharge for the 0.5 percent AEP storm event to 160,000 cfs.

The HEC-ResSim model used to establish the No Project condition at Folsom Lake was developed by USACE and is in draft form with an unknown completion date. USACE is currently refining the HEC-ResSim model used in this analysis, which will include all of the Folsom Dam JFP

modifications listed above. While incomplete, this HEC-ResSim model was selected because it is the best available model and, in general, it accurately simulates the changes to Folsom Dam and Lake. Once all storms were routed through HEC-ResSim, the time series of Folsom Dam and Lake releases were input into HEC-5, and the rest of the Sacramento River Basin was simulated.

For more information about the capabilities of this model, refer to the April 2007 *HEC-ResSim Reservoir System Simulation User's Manual* (USACE).

### **3.5.3 UNET Model Specifications**

UNET is designed to simulate 1-D, fully unsteady flow through a full network of open channels, weirs, bypasses, and storage areas. It is a fixed-bed analysis and does not account for sediment movement, scour, or deposition. UNET assumes no exchange with groundwater, but is capable of simulating levee breaks and breaches (USACE, 2002c). For more information about the capabilities of this model, refer to the August 1997 *UNET: One-Dimensional Unsteady Flow Through a Full Network of Open Channels User's Manual* (USACE) and Comprehensive Study Technical Studies Documentation, Appendix C – Hydraulic Technical Documentation (USACE, 2002d).

Separate UNET models were developed for the Sacramento River system and San Joaquin River system. The UNET models can be used to determine river flow, stage, velocity, and depth, as well as breakout and return flows from overbank areas.

Changes made to the UNET model for the 2012 CVFPP studies are documented in Attachment 8C: Riverine Channel Evaluations.

#### **Storm Events**

Inputs to the UNET model come from the HEC-5 model; therefore, the same storm centerings were used as for the Phase 2 HEC-5 hydrologic modeling, Sacramento and Vernalis.

Because only two scenarios were validated using UNET, all six (10, 4, 2, 1, 0.5, and 0.2 percent) AEP storms were run to assess the simulated effects of these scenarios on flood management. This enabled a thorough comparison of simulated effects for a range of channel flow magnitudes.

#### **Locations**

In the Sacramento River Basin, four index point locations were used to demonstrate the potential stage reduction from the two scenarios (Figure 3-10):



- Feather River and Yuba River confluence
- Feather River at Nicolaus
- Yolo Bypass at Lisbon
- Sacramento River at the I Street gage

The first two locations were selected because they are common flood management operation objectives for both Lake Oroville and New Bullards Bar Reservoir. The Yolo Bypass at Lisbon and Sacramento River at I Street gage are two of the most downstream locations and would show the systemwide effects of reservoir operational criteria changes.

In the San Joaquin River Basin, four index point locations were used to demonstrate potential stage reduction from reservoir operational criteria changes (Figure 3-11):

- San Joaquin River near Newman
- San Joaquin River at Maze Road Bridge
- San Joaquin River near Vernalis
- San Joaquin River at Stockton

The San Joaquin River Basin index points are all located downstream from the Merced River. These locations were selected because they are on the mainstem and would reflect changes to each of the five identified reservoirs' operational criteria (see Table 3-4).

Out-of-channel flow was aggregated for most reaches throughout the Sacramento and San Joaquin river basins.

2012 Central Valley Flood Protection Plan  
Attachment 8B: Reservoir Analysis

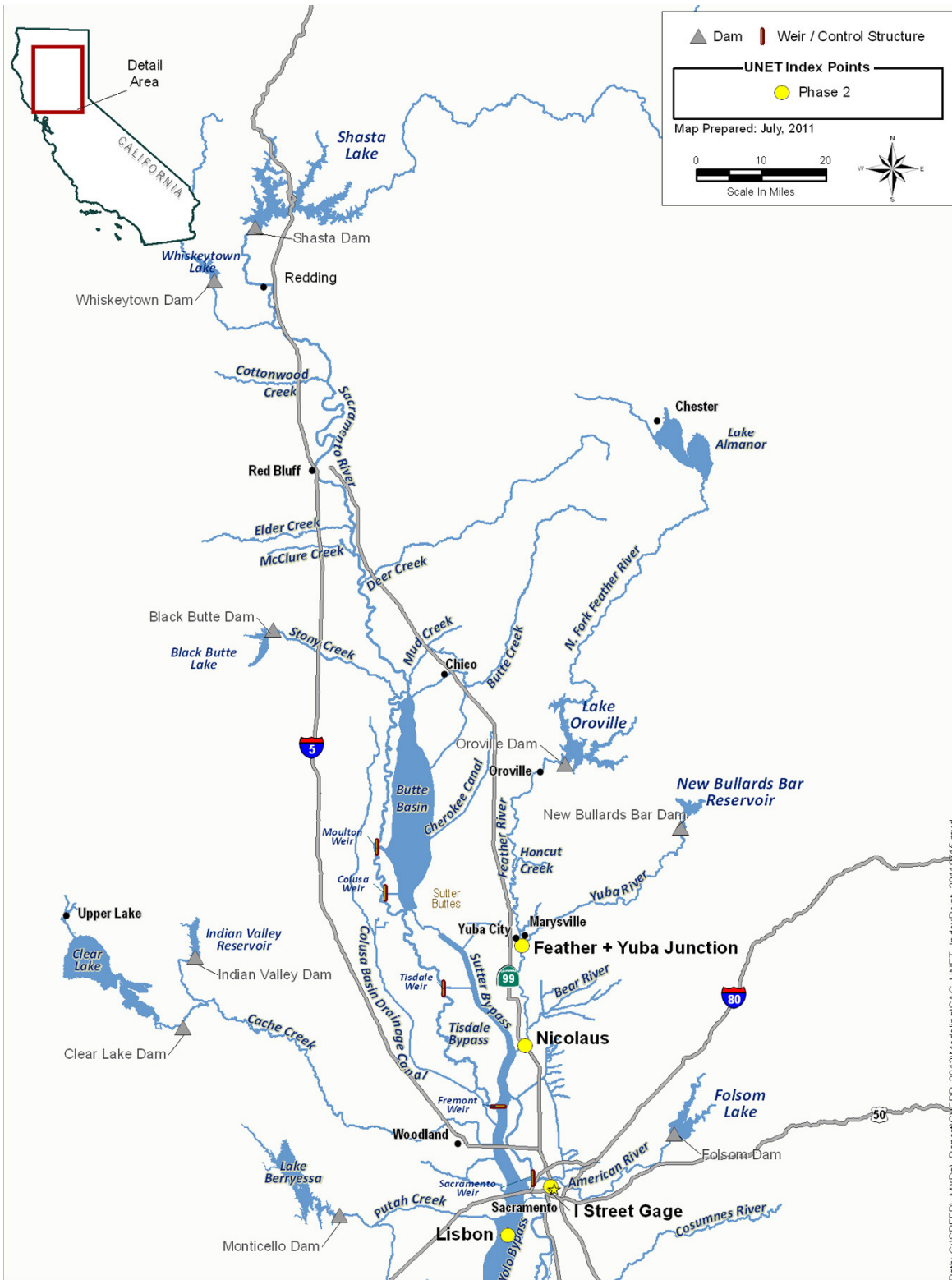


Figure 3-10. Sacramento River Basin UNET Index Point Locations

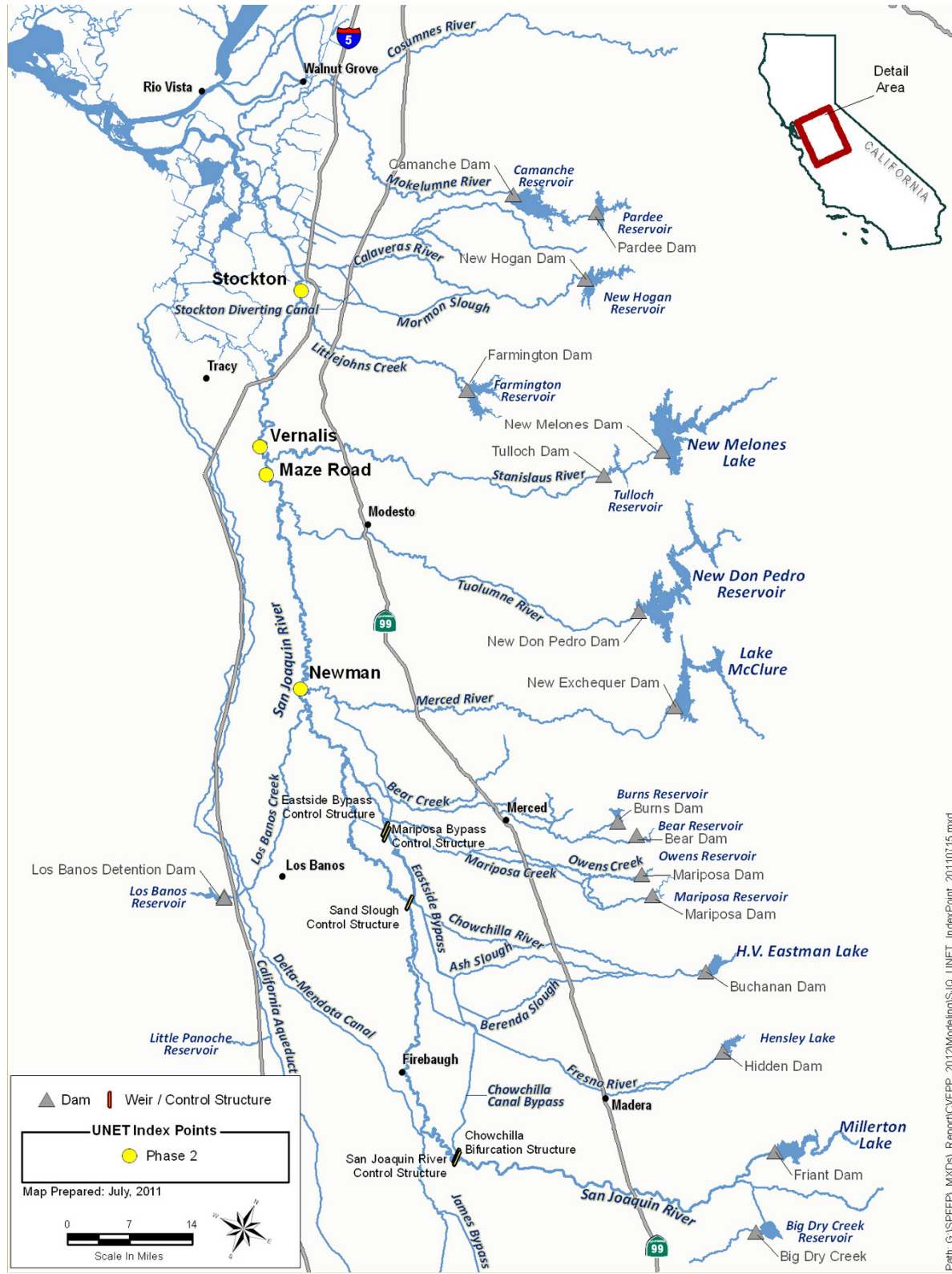


Figure 3-11. San Joaquin River Basin UNET Index Point Locations



## 4.0 No Project System Performance

This section provides an overview of No Project system performance of the Sacramento and San Joaquin river basins as simulated in HEC-5 (and supplemented by HEC-ResSim for the American River). The ability of reservoirs to manage a range of flood events under their No Project operational criteria is described.

### 4.1 Sacramento River Basin

As described in Section 3, Sacramento River Basin No Project condition includes the original Comprehensive Study HEC-5 assumptions plus the modifications associated with the Folsom Dam JFP and F-CO program.

Table 4-1 shows HEC-5 simulated results for the No Project condition compared to stated channel capacities. Striped cells in the table indicate peak flows in excess of, but within 3 percent of the channel capacity. Shaded cells in the table indicate peak flows in excess of the channel capacity. The table also shows that the current Sacramento River system can withstand different frequencies of storms, depending on location. For example, on the Feather River, system flood protection would be slightly below a 2 percent AEP storm. At the I Street gage, the objective flow was within 3 percent of its channel capacity for storms with a 1 percent or more frequent AEP.

The ability of reservoirs to operate within their objective release also varies depending on storm magnitude. For both 1 and 0.5 percent AEP Sacramento-centered storms, Shasta Lake, Lake Oroville, and Folsom Lake can operate within their objective releases. Unlike other major multipurpose reservoirs, New Bullards Bar Reservoir has a simulated inflow of 3 TAF and 64 TAF in excess of available flood storage that could not be managed for 1 and 0.5 percent AEP Sacramento-centered storms, respectively (Figure 4-1).

**Table 4-1. Simulated Sacramento River Basin Objective Flow Exceedence for No Project Condition for Sacramento-Centered Storm**

Index Point Location	Peak Flow of Flood Event (cfs)						
	Channel Capacity (cfs)	10 percent AEP	4 percent AEP	2 percent AEP	1 percent AEP	0.5 percent AEP	0.2 percent AEP
Feather and Yuba River Junction	300,000	179,717	270,028	276,070	276,712	359,036	587,901
Feather River at Nicolaus	320,000	208,764	309,737	320,129	327,445	420,103	656,064
Sacramento and Feather River Junction	410,000	323,838	444,372	473,955	499,559	614,891	877,461
Sacramento River near I Street Gage	110,000	95,224	111,611	112,268	112,167	130,042	224,649

Model: HEC-5

Note:

Striped cells indicate peak flows in excess of the channel capacity, but within 3 percent of the channel capacity.

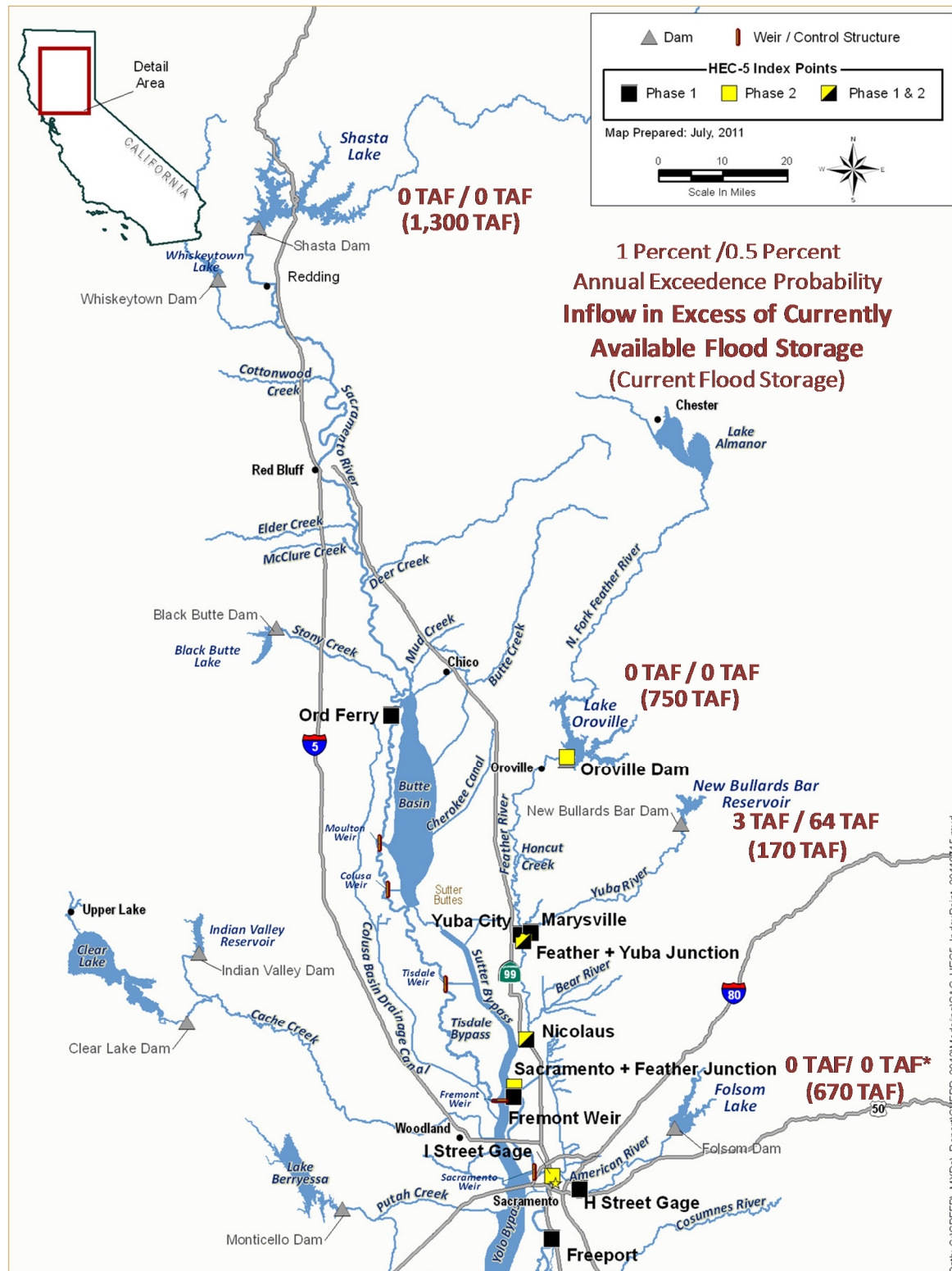
Shaded cells indicate peak flows in excess of the channel capacity.

Key:

AEP = Annual Exceedence Probability

cfs = cubic feet per second

Sacramento-Centered = Storm centered at Sacramento River at latitude of Sacramento

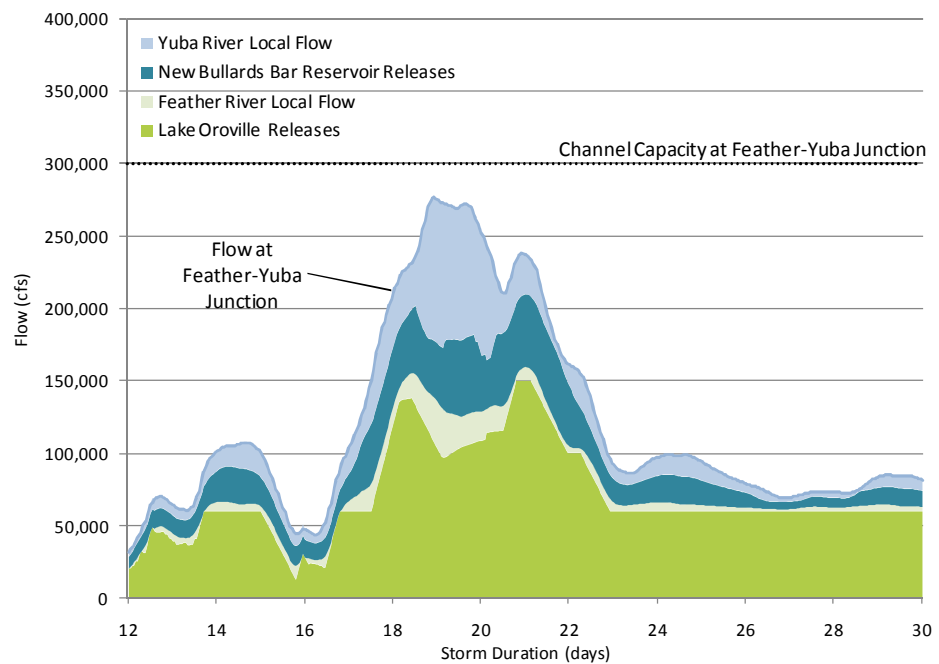


\* Note: Assumes a maximum objective release of 160,000 cfs during large storm events.

**Figure 4-1. Volume of Inflow in Excess of Currently Available Flood Storage for 1 and 0.5 Percent AEP Sacramento-Centered Storms for No Project Condition**

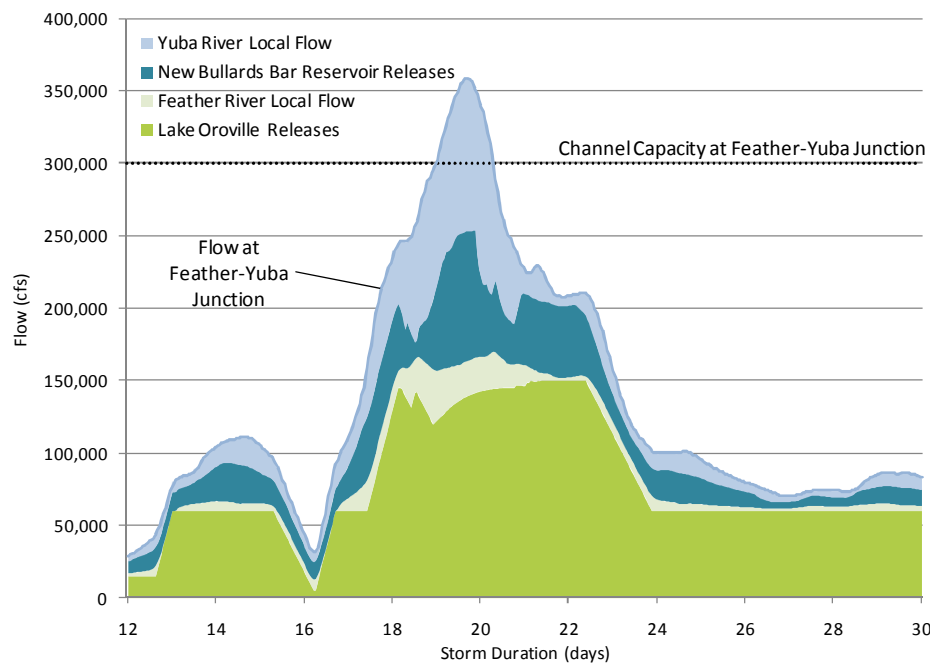


Figures 4-2 and 4-3 show the No Project condition for the Feather and Yuba rivers during 1 and 0.5 percent AEP storms. The Yuba River contributes nearly half of the flow at the confluence of the Feather and Yuba rivers, but less than half of Yuba River flow is regulated by New Bullards Bar Reservoir on the North Fork Yuba River. The figures also show that while Lake Oroville stays within its objective release of 150,000 cfs below the dam for both AEP storms, this high objective release substantially contributes to peak downstream flows.



**Figure 4-2. Simulated No Project Condition for 1 Percent AEP Sacramento-Centered Storm**





**Figure 4-3. Simulated No Project Condition for 0.5 Percent AEP Sacramento-Centered Storm**

Observations of system performance for the No Project condition during 1 and 0.5 percent AEP Sacramento-centered storms include the following:

- Lake Oroville is appropriately sized to manage at least a 0.5 percent AEP Sacramento-centered storm.
- Lake Oroville's objective flow downstream from Oroville Dam is half of the channel capacity at the confluence of the Feather and Yuba rivers.
- New Bullards Bar Reservoir exceeds its objective release during 1 and 0.5 percent AEP Sacramento-centered storms.
- Less than half of Yuba River flow is regulated by New Bullards Bar Reservoir.
- The Yuba River contributes to half or more of the peak flow at the Feather-Yuba river junction.

## 4.2 San Joaquin River Basin

No Project flow conditions in the San Joaquin River Basin were simulated using HEC-5. No changes to Comprehensive Study HEC-5 assumptions

for reservoir operational criteria for the San Joaquin River Basin were made for this analysis. Table 4-2 shows simulated peak flows in the San Joaquin River Basin at various locations on the mainstem under the six flood events resulting from a Vernalis-centered storm. Shaded cells in the table indicate peak flows in excess of the channel capacity

**Table 4-2. Simulated San Joaquin River Basin Objective Flow Exceedence for No Project Condition for Vernalis-Centered Storm**

Index Point Location	Channel Capacity (cfs)	Peak Flow of Flood Event (cfs)					
		10 percent AEP	4 percent AEP	2 percent AEP	1 percent AEP	0.5 percent AEP	0.2 percent AEP
Chowchilla Bypass near Fresno River	10,000	7,447	9,485	12,577	24,024	37,405	55,805
El Nido	16,500	12,070	16,566	22,262	36,672	62,441	98,012
Newman	45,000	21,713	27,575	32,494	62,665	98,090	154,357
At Maze Road Bridge	46,000	30,407	37,097	55,020	92,051	135,191	214,299
Near Vernalis	52,000	35,564	44,856	62,342	98,864	150,109	250,309
Stockton <sup>1</sup>	52,000*	36,883	46,582	63,128	98,194	150,627	250,132

Model: HEC-5

Note:

<sup>1</sup> HEC-5 models Stockton as downstream from the confluence of the San Joaquin River and Littlejohns Creek, and no flow is diverted to other tributaries. Assumed channel capacity would remain the same as at Vernalis. Shaded cells indicate peak flows in excess of the channel capacity.

Key:

AEP = annual exceedence probability

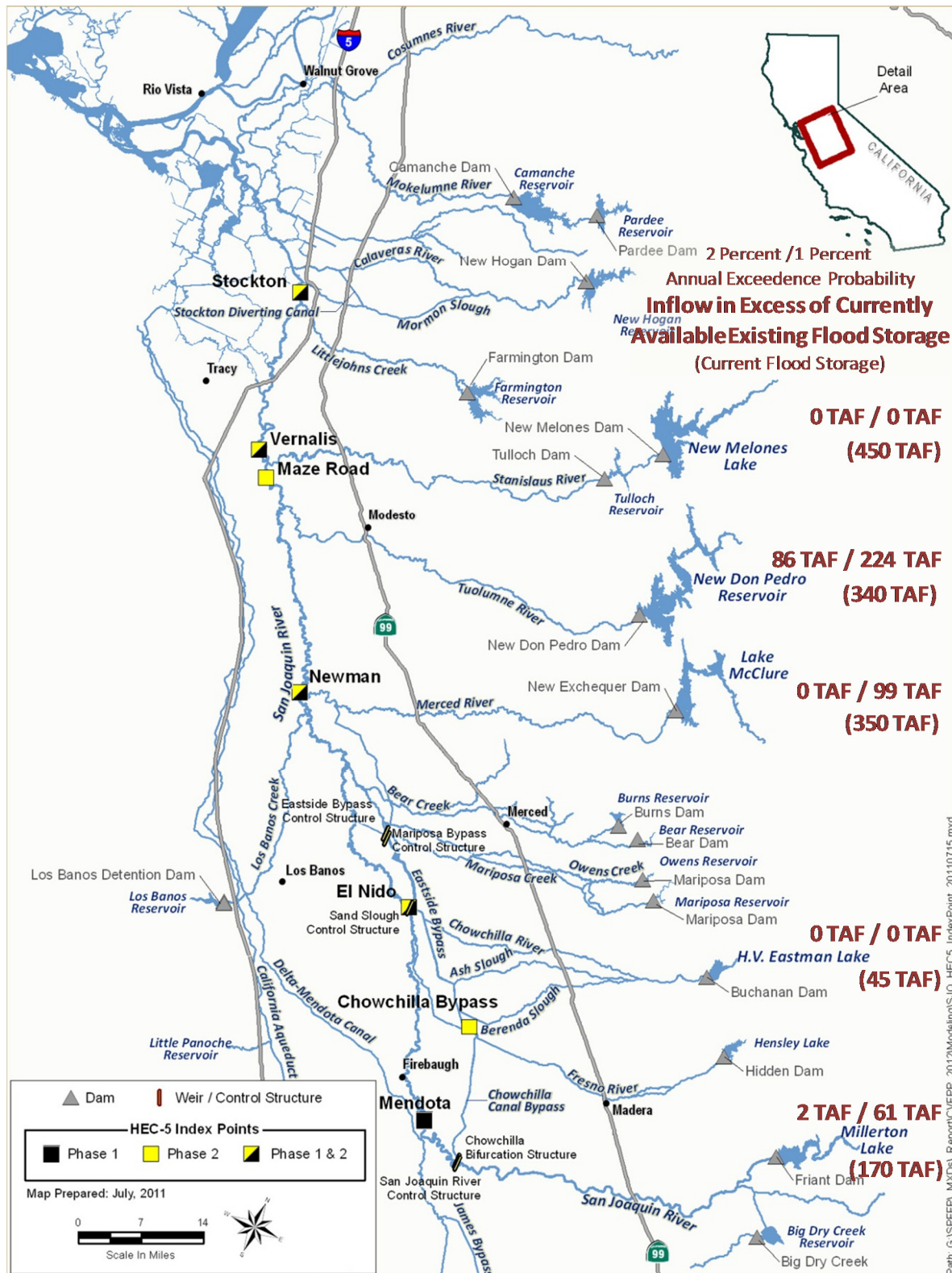
cfs = cubic feet per second

Vernalis-Centered = Storm centered at San Joaquin River at latitude of Vernalis

According to the HEC-5 simulation, at most locations, the San Joaquin River system capacity is only sufficient for storms at or more frequent than a 4 percent AEP. For a 2 percent AEP Vernalis-centered storm, only three of the five major multipurpose flood reservoirs are able to operate without exceeding objective releases. Millerton Lake and New Don Pedro Reservoir have a simulated 2 TAF and 86 TAF, respectively, of inflow in excess of available flood storage (Figure 4-4).

For a 1 percent AEP Vernalis-centered storm, Millerton Lake and New Don Pedro Reservoir are unable to stay within their objective releases, and have 61 TAF and 224 TAF more inflow, respectively, than they can manage (Figure 4-4). Lake McClure also has a simulated inflow of 99 TAF in excess of available flood storage.

#### 4.0 No Project System Performance

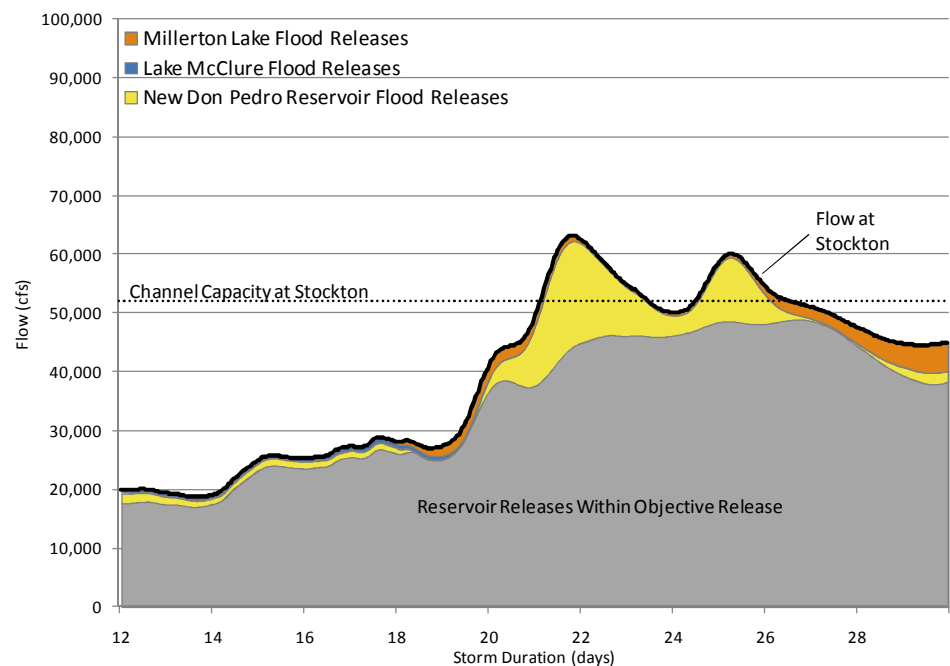


**Figure 4-4. Volume of Inflow in Excess of Currently Available Flood Storage for 2 and 1 Percent AEP Vernalis-Centered Storms for No Project Condition**

H.V. Eastman and New Melones reservoirs are able to operate within their objective releases for both the 2 and 1 percent AEP storms.

When a reservoir makes releases in excess of objective release targets, it almost always exceeds the channel capacity just downstream from the reservoir and also has a higher potential to contribute to exceeding channel capacity downstream in the river system. Unlike the Sacramento River Basin, which has a complex system of weirs and bypasses, the majority of reservoir releases in the San Joaquin River Basin flow directly into the mainstem San Joaquin River. As a result, it is possible to evaluate the impact of reservoir releases above objective flow targets on the system at a reconnaissance level.

For a 2 percent AEP Vernalis-centered storm, channel capacity in the San Joaquin River at Stockton is exceeded under the No Project condition (Figure 4-5). If all of the multipurpose reservoirs operated within their objective releases, channel capacity at Stockton would not be exceeded, as shown by the grey shaded area. H.V. Eastman and New Melones reservoirs are not shown in the figure because they operate within the objective release (i.e., no flood releases). Releases from New Don Pedro Reservoir above its Tuolumne River flow objective were the main contributor to channel capacity in Stockton being exceeded.

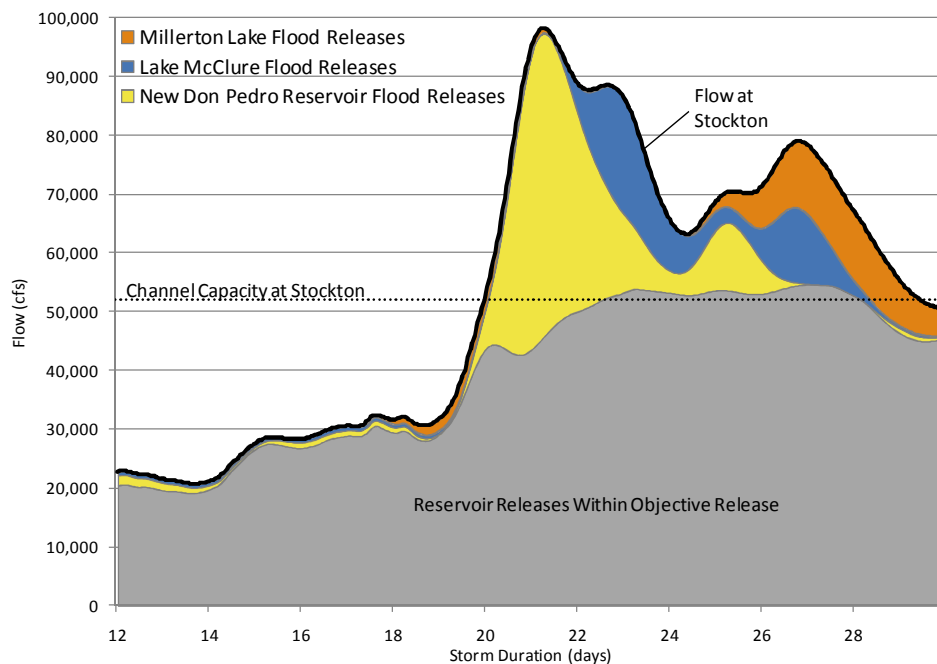


Note:

Reservoir flood releases mean reservoir releases are above their objective releases.

**Figure 4-5. Simulated Reservoir Contributions to Flow at Stockton for 2 Percent AEP Vernalis-Centered Storm for No Project Condition**

As shown in Figure 4-6, for a 1 percent AEP storm, the highest peak flow in the San Joaquin River at Stockton is predominantly influenced by New Don Pedro Reservoir. Lake McClure and Millerton Lake also release flows above their objective releases and contribute to high flows at Stockton, but their contributions occur later in the storm event and do not affect the highest peak flow at Stockton. If the reservoirs were operated to not exceed their objective releases, flows at Stockton would be close to staying within the channel capacity (as shown by the top of the grey shaded area being close to the dotted channel capacity line).



Note:

Reservoir flood releases mean reservoir releases are above their objective releases.

**Figure 4-6. Simulated Reservoir Contributions to Flow at Stockton for 1 Percent AEP Vernalis-Centered Storm for No Project Condition**

New Don Pedro Reservoir contributes the largest volume of floodflow into the system. However, even if all reservoirs operate within their objective releases, flows at Stockton would remain well above channel capacity for storms of greater magnitude.

The following observations were made regarding the reservoirs' current operational criteria and were used to guide the magnitude and location of strategic reservoir operational criteria changes based on review of current reservoir operational criteria during 2 and 1 percent AEP storms:

- New Don Pedro Reservoir has the largest volume of inflow that cannot be managed for the hydrology used in this analysis.

- New Don Pedro Reservoir is the sole contributor to peak flow at Stockton for a 1 percent AEP Vernalis-centered storm.
- H.V. Eastman and New Melones reservoirs do not exceed their respective objective release targets for either Vernalis-centered storm frequency.
- Lake McClure is appropriately sized to manage a 2 percent AEP Vernalis-centered storm.
- The effect of Millerton Lake exceeding its objective release for San Joaquin River flows in Stockton is not observed until late in the simulated storm because of the long travel distance.

## 5.0 Basin-Wide Sensitivity to Changes in Reservoir Operational Criteria

This section summarizes the sensitivity of reservoir operational criteria changes on individual and basin-wide bases. First, multiple changes were made to reservoirs' operational criteria to determine how the reservoirs and the system would react to operational criteria changes. Next, the operational criteria changes were incrementally refined to determine which modifications were most effective in yielding flood risk management benefits. Lastly, as described in Section 6, the operational criteria changes that yielded high flood benefits, as simulated in HEC-5, were used to identify the two scenarios considered for the Enhance Flood System Capacity Approach.

Changes in reservoir operational criteria were simulated in HEC-5 for multipurpose reservoirs within the Central Valley. Operational criteria changes explored in this analysis included the following:

- Changes to the flood management rule curves (i.e., increasing the amount of space dedicated to flood storage)
- Changes to the objective flow to which a reservoir is operated
- Changes to the reservoir release diagram
- Addition of coordinated reservoir operating locations

### 5.1 Sacramento River Basin Operational Criteria Changes

The basin-wide sensitivity analysis was completed in two phases (as described in Section 3). Phase 1 explored how the system would react to simultaneous operational criteria changes at multiple reservoirs and identified which reservoirs have the greatest potential to benefit the system. Phase 2 made incremental operational criteria changes to the identified reservoirs.

The 16 scenarios from Phase 1 and Phase 2 in the Sacramento River Basin are summarized in Table 5-1. During the Phase 1 analysis, six scenarios with modified operational criteria at Lake Oroville, New Bullards Bar Reservoir, Folsom Lake, and Shasta Lake were run.

### **5.1.1 Phase 1**

Main findings and recommendations from Phase 1 of the 2012 CVFPP Reservoir Analysis in the Sacramento River Basin are summarized as follows:

- The Feather-Yuba River Basin is potentially sensitive to operational criteria changes. Modifications to Lake Oroville and New Bullards Bar Reservoir resulted in peak flow reduction in the Feather-Yuba River Basin. Although attenuated, similar effects were observed on the Sacramento River and in the Yolo Bypass.
- There was no noticeable effect from operational criteria changes to Shasta Lake and Folsom Lake.
- Phase 2 of the 2012 CVFPP Reservoir Analysis should focus on Lake Oroville and New Bullards Bar Reservoir.

### **5.1.2 Phase 2**

For Phase 2, 10 scenarios with modified Lake Oroville and New Bullards Bar Reservoir operational criteria were run. One scenario that modified Lake Oroville operational criteria was identified during Phase 2 for the Sacramento River Basin and is discussed in further detail in Section 7.

Shasta Lake operational criteria changes were not explored in Phase 2 because of the large magnitude of unregulated flows entering from tributaries downstream from Shasta Lake that overwhelms changes made to Shasta Lake operational criteria. For example, the simulated 1 percent AEP storm peak flow for the No Project condition from Shasta Lake was 74,000 cfs, while its downstream tributary, Cottonwood Creek, had a larger peak flow of 97,400 cfs for the same storm.

Folsom Lake operational criteria changes were not explored in Phase 2 because Folsom Lake operational criteria have recently been changed through the Folsom Dam JFP. These modifications were included in the No Project condition model.



**Table 5-1. Sacramento River Basin Reservoir Operational Criteria Changes and Peak Flow Reduction for 1 Percent AEP Sacramento-Centered Storm**

	Scenario	Flood Storage Added by Reservoir <sup>1</sup> (1,000 acre-feet)					Shasta Lake Objective Release Changes (cfs)	Lake Oroville Release Schedule Changes <sup>2</sup>	Description	Peak Flow Reduction (percent) <sup>3</sup>	
		Lake Oroville	New Bullards Bar Reservoir	Folsom Lake	Shasta Lake	Total				At Nicolaus	At Freeport
Phase 1	SAC-1	100	50			150			Evaluate the sensitivity of each reservoir to flows in the Sacramento River Basin.	2.1	0.1
	SAC-2	150	50			200				1.0	0.1
	SAC-3	250	100			350				0.2	0.2
	SAC-4	250	100	107		457				0.2	0.2
	SAC-5	250	100		500	850				0.2	0.2
	SAC-6	250	100		500	850	79,000 to 75,000			0.2	0.2
Phase 2	SAC-7	100	100			200			Combine Lake Oroville and New Bullards Bar Reservoir.	2.1	0.1
	SAC-8	250	150			400				0.2	0.2
	SAC-9	500	200			700				2.2	0.5
	SAC-10		100			100			Isolate New Bullards Bar Reservoir effects.	0.0	0.1
	SAC-11		150			150		C		2.5	-0.5
	SAC-12	100				100		A	Isolate Lake Oroville effects.	1.7	0.4
	SAC-13	200				200				-0.1	0.1
	SAC-14	200				200		B		-0.4	0.6
	Sacramento Scenario	200				200		C		3.8	-1.0
	SAC-15	200	50			250		C	Combine Lake Oroville and New Bullards Bar Reservoir operational criteria changes.	4.4	-0.8

Note:

<sup>1</sup> Blank cells represent no changes to operational criteria.

<sup>2</sup> See Lake Oroville Release Schedule Modifications Table (Table 5-2) for more details.

<sup>3</sup> Negative peak flow reductions correspond to an increase in peak flow.

Key:

AEP = annual exceedence probability

cfs = cubic feet per second

SAC = Sacramento

### 5.1.3 Oroville Dam and Lake Oroville

The Feather River is sensitive to changes in Lake Oroville's operational criteria. Currently, Lake Oroville can operate near its objective release for up to a 0.5 percent AEP Sacramento-centered storm. Despite both Lake Oroville and New Bullards Bar Reservoir operating within their objective releases, downstream channel capacities at some locations are exceeded during a 1 percent AEP Sacramento-centered storm.

During the basin-wide sensitivity analysis, Lake Oroville's flood storage allocation was increased, but this did not produce a noticeable reduction in reservoir releases. The release schedule of a reservoir is not only a function of storage in the reservoir, but also inflow into the reservoir. As a result, the release schedule at Lake Oroville was modified such that the maximum objective release of 150,000 cfs would not occur until there was a higher reservoir inflow than under current conditions. This change was made in conjunction with an increase in flood storage to allow the reservoir to manage more water while still permitting releases to be governed by inflow rather than operational criteria for flood pool. Three release schedule modifications were explored (Table 5-2).

**Table 5-2. Lake Oroville Release Schedule Modifications**

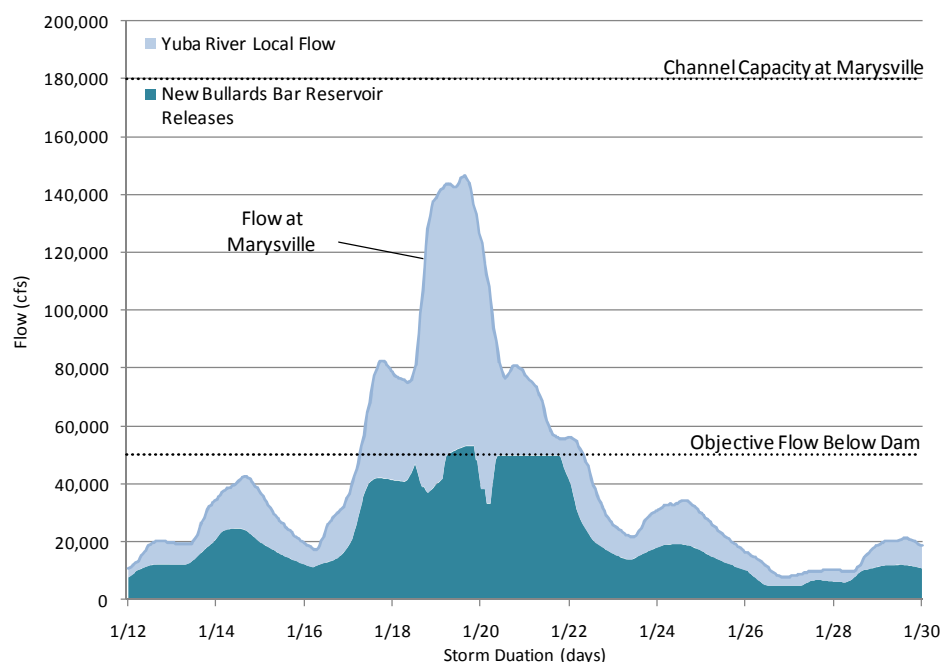
No Project		A		B		C	
Inflow (cfs)	Release Capacity (cfs)	Inflow (cfs)	Release Capacity (cfs)	Inflow (cfs)	Release Capacity (cfs)	Inflow (cfs)	Release Capacity (cfs)
1	15,000	1	15,000	1	15,000	1	15,000
30,000	15,000	30,000	15,000	30,000	15,000	30,000	15,000
30,005	60,000	30,005	70,000	30,005	60,000	30,005	60,000
120,000	60,000	120,000	70,000	120,000	60,000	120,000	60,000
120,005	100,000	120,005	100,000	120,005	80,000	120,005	80,000
175,000	100,000	175,000	100,000	200,000	80,000	300,000	80,000
175,005	150,000	175,005	150,000	200,005	150,000	300,005	150,000
900,000	150,000	900,000	150,000	900,000	150,000	900,000	150,000

Key:  
cfs = cubic feet per second

### 5.1.4 New Bullards Bar Dam and Reservoir

For the No Project condition, New Bullards Bar Reservoir is generally able to operate within its objective release criteria for 1 percent AEP or more frequent storms. Operational criteria changes to New Bullards Bar Reservoir could lower its peak releases, but its effect on the system is minimal. As shown in Figure 5-1, less than half of the Yuba River flow at

Marysville is regulated by New Bullards Bar Reservoir on the North Yuba River; the remaining flow comes from the unregulated Middle and South Yuba rivers. Because New Bullards Bar Reservoir regulates less than half of the Yuba River flows, operational criteria changes did not produce large downstream flood risk management benefits.



**Figure 5-1. Yuba River Flow for 1 Percent AEP Sacramento-Centered Storm – No Project Condition**

For more infrequent storms (0.5 and 0.2 percent AEPs), when New Bullards Bar Reservoir would be forced to make releases in excess of objective release targets, additional flood storage does improve downstream channel flow conditions. Adding flood storage would allow the reservoir to release flows closer to its objective release targets. For example, adding 100 TAF of storage decreases flow at Marysville from approximately 195,800 cfs to 186,500 cfs for a 0.5 percent AEP Sacramento-centered storm.

## 5.2 San Joaquin River Basin Operational Criteria Changes

The 33 scenarios from Phase 1 and Phase 2 in the San Joaquin River Basin are summarized in Table 5-3. During the Phase 1 analysis, 17 scenarios were run that modified operational criteria at Millerton Lake, H.V. Eastman Lake, Lake McClure, New Melones Reservoir, and New Don Pedro Reservoir.

**Table 5-3. San Joaquin River Basin Reservoir Operational Criteria Changes and Peak Flow Reduction for 1 Percent AEP Vernalis-Centered Storm**

Scenario	Flood Storage Added by Reservoir <sup>1</sup> (1,000 acre-feet)						Objective Release Changes by Reservoir (cfs)	Description	Peak Flow Reduction at Stockton (percent) <sup>2</sup>
	Millerton Lake	H.V. Eastman Lake	Lake McClure	New Don Pedro Reservoir	New Melones Reservoir	Total			
Phase 1	A-1		45		100	145		No Millerton Lake changes.	0
	B-1	25				25		Isolate Millerton Lake effects.	0
	C-1	50				50			0
	C-2	50				50	New Don Pedro Reservoir: 9,000 to 11,000	Combine upper San Joaquin River reservoirs.	9
	C-3	50		25	50	125			6
	C-4	50		25		100			11
	C-5	50		25		100	New Melones Reservoir: 8,000 to 6,000		13
	C-6	50		50		100			6
	C-7	50		50		100	Lake McClure: 6,000 to 5,000		6
	D-1	85				85			1
	D-2	85	45			130		Isolate Millerton Lake effects.	1
	D-3	85	45			130	New Melones Reservoir: 8,000 to 6,000	Combine upper San Joaquin River reservoirs.	8
	D-4	85	45		100	230			10
	D-5	85	45		100	230			1
	D-6	85	45	25	100	255			6
	D-7	85	45	100		230			1
	D-8	85	45	100	150	380			6

**Table 5-3. San Joaquin River Basin Reservoir Operational Criteria Changes and Peak Flow Reduction for 1 Percent AEP Vernalis-Centered Storm (contd.)**

Scenario	Flood Storage Added by Reservoir <sup>1</sup> (1,000 acre-feet)						Objective Release Changes by Reservoir (cfs)	Description	Peak Flow Reduction at Stockton (percent) <sup>2</sup>
	Millerton Lake	H.V. Eastman Lake	Lake McClure	New Don Pedro Reservoir	New Melones Reservoir	Total			
Phase 2	SJQ-1	300				300		Assume construction of Temperance Flat Dam.	3
	SJQ-2			25		25		Isolate Lake McClure effects.	0
	SJQ-3			50		50			0
	SJQ-4			100		100			0
	SJQ-5			150		150			0
	SJQ-6				25	25		Isolate New Don Pedro Reservoir effects.	5
	SJQ-7			100		100			10
	SJQ 7a			230		230			20
	SJQ-8			275		275			20
	SJQ-9			300		300			20
	SJQ-10					0	New Don Pedro Reservoir: 9,000 to 12,000		7
	SJQ-11			160		160	New Don Pedro Reservoir: 9,000 to 12,000		16
	San Joaquin Scenario	60		100	230	390		Combine effect of reservoirs based on volume of unmanageable inflow.	34
	SJQ-12	100		150	300	550			44
	SJQ-13			100	230	330			25
	SJQ-14 <sup>3</sup>			100	230	330		Include coordination operations.	25

Note:

<sup>1</sup> Blank cells represent no changes to operational criteria.

<sup>2</sup> Rounded to the nearest percent.

<sup>3</sup> Added coordinated operation point at Maze Road for Lake McClure and New Don Pedro Reservoir.

Key:

AEP = annual exceedence probability

cfs = cubic feet per second

### **5.2.1 Phase 1**

The main findings and recommendations from Phase 1 of the 2012 CVFPP Reservoir Analysis in the San Joaquin River Basin are summarized as follows:

- Even after operational criteria changes, simulated peak flows at some locations exceeded assumed channel capacity in all storm events, except events of 4 percent AEP and smaller. Peak flows at these locations were results of hydrologic routing, which does not reflect levee breaches as in hydraulic models. These results are indicative but not predictive of how flow could change.
- Further hydraulic modeling is recommended as necessary to better understand changes to mainstem flow through reservoir operational criteria changes.

### **5.2.2 Phase 2**

For Phase 2, 16 scenarios with modified Millerton Lake, Lake McClure, and New Don Pedro Reservoir operational criteria were run.

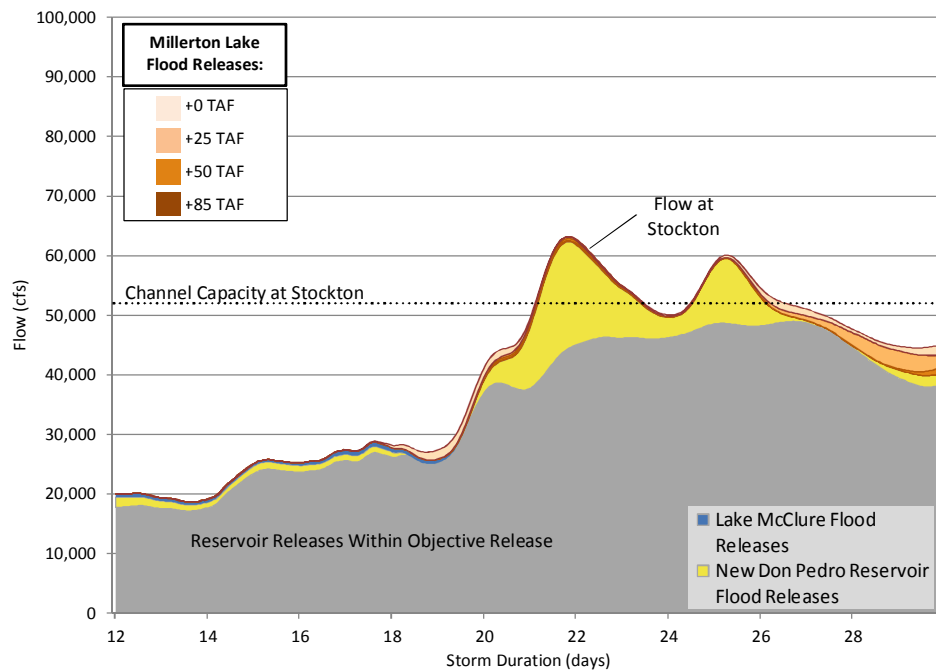
H.V. Eastman Lake operational criteria changes were not made in Phase 2 because increasing the volume of H.V. Eastman Lake's flood reservation space did not provide any additional benefits in peak flow reduction in the San Joaquin River at Stockton (as shown in the Phase 1 analysis).

No additional simulations were run that included New Melones Reservoir in Phase 2 because the reservoir has a large storage volume compared to the volume of inflow into the reservoir. The sensitivity of increasing the flood storage allocation among the three upper San Joaquin River reservoirs (including New Melones Reservoir) is briefly discussed later in this section. As a result, one scenario that modified a combination of Millerton Lake, Lake McClure, and New Don Pedro Reservoir operational criteria changes was identified during Phase 2 for the San Joaquin River Basin and is discussed in further detail in Section 6.

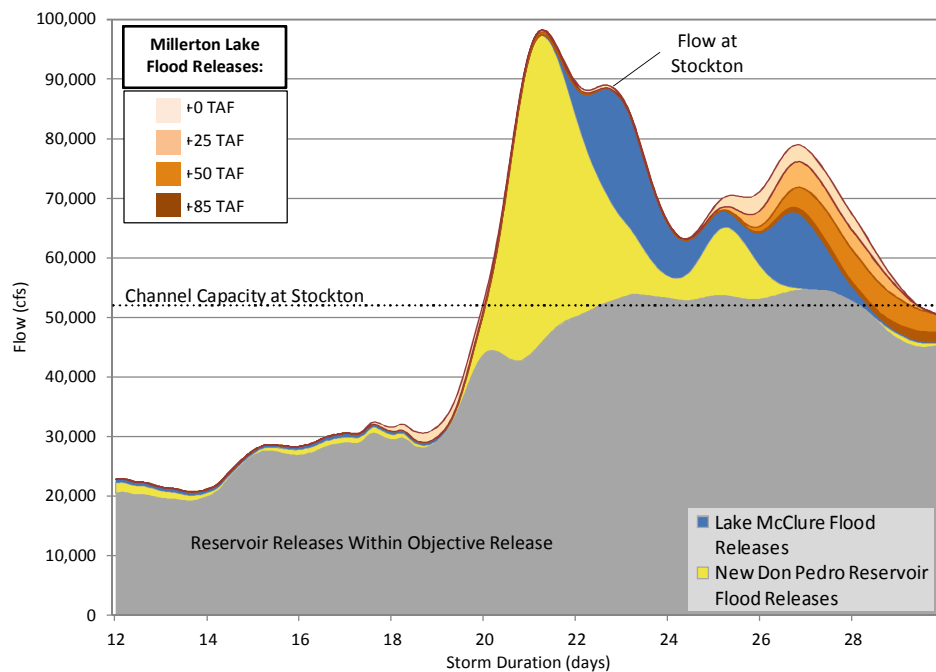
### **5.2.3 Friant Dam and Millerton Lake**

As described earlier, Millerton Lake is almost capable of operating within its objective release for a 2 percent AEP Vernalis-centered storm but is unable to manage all of the 1 percent AEP storm inflow with its current 170 TAF allocation of flood storage. Figures 5-2 and 5-3 show the effects of adding three increments of flood storage to Millerton Lake.

## 5.0 Basin-Wide Sensitivity to Changes in Reservoir Operational Criteria



**Figure 5-2. Comparison of Effects at Stockton from Additional Flood Storage Increments at Millerton Lake for 2 Percent AEP Vernalis-Centered Storms**



**Figure 5-3. Comparison of Effects at Stockton from Additional Flood Storage Increments at Millerton Lake for 1 Percent AEP Vernalis-Centered Storms**

The largest simulated effects occurred when flood storage was increased by 50 percent (from 170 TAF to 255 TAF). For the 1 percent AEP storm, simulated peak flow decreased by a maximum of 5,703 cfs, but flow remained above channel capacity for nearly the same duration for the No Project condition at Stockton; peak flow decreased by only 3 hours for a 1 percent AEP storm.

Table 5-4 shows that of the three scenarios, the largest benefit relative to the increase in flood storage allocation was when 85 TAF of flood storage was added to Millerton Lake flood storage allocation.

### **5.2.1 San Joaquin River Reservoirs**

The sensitivity of allocating the same magnitude of additional flood storage at different reservoirs was further explored using HEC-5 runs from Phase 1. Increasing the flood storage allocation by 100 TAF at Lake McClure and New Don Pedro and New Melones reservoirs had different effects on the system. Under the No Project condition, both New Melones Reservoir and Lake McClure can manage a 2 percent AEP storm, and New Melones Reservoir can manage a 1 percent AEP storm. Hence, it was expected and confirmed that adding more flood storage allocation would have limited downstream effects. Reservoir operational criteria changes have less effect on the flood management systems if a reservoir is already capable of managing flood inflows (i.e., the objective release is not exceeded).

Table 5-5 shows that because New Don Pedro Reservoir has the largest volume of floodflow that cannot be managed, this reservoir showed the greatest downstream benefit from an increased flood storage allocation. Changes to the objective releases of the reservoirs, in combination with increased flood storage allocations, were explored in Phase 1, but did not noticeably affect peak downstream flows.



**Table 5-4. Effects of Additional Flood Storage Allocation at Millerton Lake for 2 and 1 Percent AEP Vernalis-Centered Storm**

Total Added Storage (TAF)	Peak Flow at Stockton				Stockton Channel Capacity Exceeded				At Stockton	
	Rate (cfs)		Percent Reduction		Duration (hours)		Percent Reduction		Peak Flow Reduction Index <sup>1</sup>	Unit Performance Index <sup>2</sup> (percent)
	2 percent	1 percent	2 percent	1 percent	2 percent	1 percent	2 percent	1 percent		
0	63,128	98,194	N/A	N/A	106	227	N/A	N/A	N/A	N/A
25	63,232	98,285	0	0	97	225	8	1	-0.1 <sup>3</sup>	-0.4
50	62,930	97,902	0	0	95	222	10	2	0.1	0.1
85	62,532	97,548	1	1	92	202	13	11	0.3	0.4

Model: HEC-5

Notes:

<sup>1</sup> Peak Flow Reduction Index =  $\sum [ (\text{Percent Reduction}_{\text{AEP}, i}) \times (\text{AEP}, i) ] / [ \sum (\text{AEP}, i) ] \times 100$

<sup>2</sup> Unit Performance Index = Peak Flow Reduction Index / Total TAF

<sup>3</sup> Indices are negative because for some AEPs, peak flow increased at Stockton because the shift in flows at Millerton Lake, combined with the peak flows from other tributaries, resulted in greater downstream peak flows.

Key:

AEP = annual exceedence probability

cfs = cubic feet per second

N/A = not applicable

TAF = thousand acre-feet

### **5.2.1 New Don Pedro Dam and Reservoir**

Because operational criteria changes to New Don Pedro Reservoir yielded the greatest downstream benefit, three types of operational criteria changes were preliminarily explored: required flood storage allocation increases, objective release increases, and coordinated operations with Lake McClure.

#### ***Increase in Flood Storage Allocation***

Increasing flood storage allocation at New Don Pedro Reservoir resulted in flood management benefits. Varying allocations of flood storage were added to New Don Pedro Reservoir to observe their effects on the system.

As shown in Figure 4-4, New Don Pedro Reservoir has a simulated 224 TAF of inflow during a 1 percent AEP Vernalis-centered storm in excess of available storage. To determine whether increasing the flood storage allocation by an equivalent amount would yield flood risk management benefits, 230 TAF of flood storage allocation was added. Figure 5-4 shows that this has a substantial impact on the magnitude of flows and the duration of time that channel capacity is exceeded. To confirm that the volume of flood inflow exceeding available storage is directly related to changes in downstream peak flow, a suite of additional flood storage allocation scenarios were simulated. Reduction in flow and the duration of time that channel capacity is exceeded occurs as more flood storage is allocated to New Don Pedro Reservoir, but this relationship is not linear. The largest benefit is realized when 230 TAF of flood storage is added; flow remains within channel capacity for a 2 percent AEP Vernalis-centered storm and peak flows decrease by nearly 20,000 cfs for a 1 percent AEP storm. The incremental benefit tapers off as additional flood storage is allocated.

The peak flow reduction index and unit performance index are lower for these scenarios compared to operational criteria changes for other reservoirs, such as at Millerton Lake (Table 5-6). Because these indices are weighted by storm AEP, and the largest benefit from peak flow reduction occurs for less frequent storms, the benefit derived from New Don Pedro Reservoir operational criteria changes may be considered understated.

#### ***Objective Release Changes***

To minimize the volume of additional flood storage allocation while still reducing downstream flow, an increase in the objective release from New Don Pedro Reservoir was also explored. Effects of changes to the objective release on the system varied, depending on the frequency of the storm.

**Table 5-5. Effects of Additional Flood Storage Allocation for 2 and 1 Percent AEP Vernalis-Centered Storm**

Add 100 TAF of Storage to	Total Added Storage (TAF) <sup>1</sup>	Peak Flow at Stockton				Stockton Channel Capacity Exceeded				At Stockton	
		Rate (cfs)		Percent Reduction		Duration (hours)		Percent Reduction		Peak Flow Reduction Index <sup>2</sup>	Unit Performance Index <sup>3</sup> (percent)
		2 percent	1 percent	2 percent	1 percent	2 percent	1 percent	2 percent	1 percent		
N/A	130	62,617	97,669	0	0	87	201	0	0	0	0
McClure	230	62,617	97,583	1	1	87	201	18	11	0.5	0.2
New Don Pedro	230	55,740	87,892	12	10	27	184	75	19	1.9	0.8
New Melones	230	62,617	97,669	1	1	87	201	18	11	0.7	0.3

Model: HEC-5

Notes:

<sup>1</sup> Includes increasing flood storage allocation by 85 TAF and 45 TAF to Millerton Lake and H.V. Eastman Lake, respectively.

<sup>2</sup> Peak Flow Reduction Index =  $\sum [ (\text{Percent Reduction}_{\text{AEP}, i}) \times (\text{AEP}, i) ] / [ \sum (\text{AEP}, i) ] \times 100$

<sup>3</sup> Unit Performance Index = Peak Flow Reduction Index / Total TAF

Key:

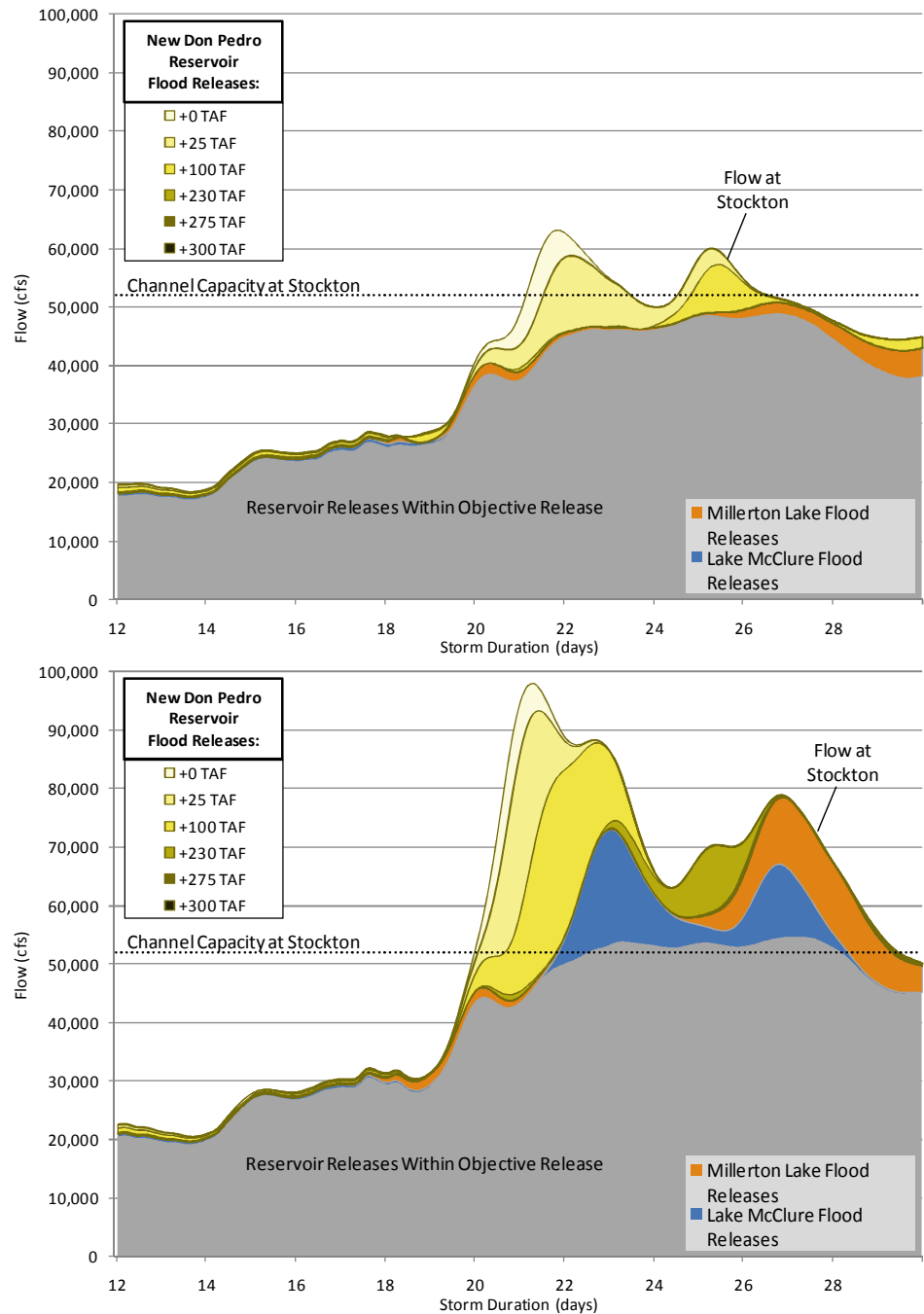
AEP = annual exceedence probability

cfs = cubic feet per second

N/A = not applicable

TAF = thousand acre-feet

**2012 Central Valley Flood Protection Plan  
Attachment 8B: Reservoir Analysis**



**Figure 5-4. Comparison of Effects at Stockton from Additional Flood Storage Allocation Increments at New Don Pedro Reservoir for 2 and 1 Percent AEP Vernalis-Centered Storm**

**Table 5-6. Effects of Operational Criteria Changes at New Don Pedro Reservoir for 2 and 1 Percent AEP Vernalis-Centered Storm**

Total Added Storage (TAF)	Peak Flow at Stockton				Stockton Channel Capacity Exceeded				At Stockton	
	Rate (cfs)		Percent Reduction		Duration (hours)		Percent Reduction		Peak Flow Reduction Index <sup>1</sup>	Unit Performance Index <sup>2</sup> (percent)
	2 percent	1 percent	2 percent	1 percent	2 percent	1 percent	2 percent	1 percent		
0	63,128	98,194	N/A	N/A	106	227	N/A	N/A	N/A	N/A
25	60,066	93,525	5	5	97	226	8	0	0.9	3.6
100	57,401	87,943	9	10	42	212	60	7	1.9	1.9
230	50,878	78,972	19	20	0	184	100	19	3.7	1.6
275	50,878	78,770	19	20	0	184	100	19	3.8	1.4
300	50,878	78,589	19	20	0	180	100	21	3.9	1.3

Model: HEC-5

Notes:

<sup>1</sup> Peak Flow Reduction Index =  $\sum [ (\text{Percent Reduction}_{\text{AEP}, i}) \times (\text{AEP}, i) ] / [ \sum (\text{AEP}, i) ] \times 100$

<sup>2</sup> Unit Performance Index = Peak Flow Reduction Index / Total TAF

Key:

AEP = annual exceedence probability

cfs = cubic feet per second

N/A = not applicable

TAF = thousand acre-feet

Increasing objective releases allows a reservoir to release higher volumes of water earlier in a storm, increasing the available reservoir storage in anticipation of high inflows later on. This change would ideally evacuate enough storage that the reservoir would not have to exceed its objective release targets. It is important to note that objective release targets are often based on channel capacity; increasing the objective release would likely require improving the channels to increase channel capacity.

New Don Pedro Reservoir currently operates within its objective release, and channel capacity is not exceeded at Stockton for more frequent storms (10 and 4 percent AEPs). As a result, increasing the objective release had negative effects on downstream channel flow. Increasing the objective release by 3,000 cfs resulted in the average release from New Don Pedro Reservoir increasing by 3,000 cfs, and an associated higher downstream channel flow.

For larger storm events (2 percent AEP and less frequent AEPs), New Don Pedro Reservoir exceeds its objective release under current operating rules. Increasing the objective release slightly lowered the peak flow, but increased the duration of time that the downstream channel capacity was exceeded.

#### ***Increase in Flood Storage Allocation and Objective Release***

The basin-wide sensitivity analysis also considered simultaneously increasing both flood storage allocation and objective release at New Don Pedro Reservoir to lower the peak release and decrease the volume of unmanageable flood inflow into the reservoir.

In summary, increasing the flood storage allocation by 160 TAF had two effects:

1. **Lowered peak flow** – More space was available to capture flood inflow and, hence, the reservoir could make lower releases.
2. **Decreased duration of flow above downstream channel capacity** – The duration of time the New Don Pedro Reservoir releases were in excess of objective release targets was much shorter than under current operational criteria, and reservoir releases were lower. Lower peak releases, when combined with mainstem flows, decreased the duration of time that downstream flows were greater than capacity.

Increasing the objective release by 3,000 cfs had two effects:

1. **Lowered peak flow** – More space could be maintained to capture high flood inflow and, hence, the reservoir could make lower releases throughout a storm event.

2. **Increased duration of time above downstream channel capacity** – Higher objective reservoir releases, when combined with mainstem flows, increased the duration of time that downstream flows were higher.

Increasing the objective release by 3,000 cfs and flood storage allocation by 160 TAF had two effects:

1. **Lowered peak flow** – More space was available to capture high flood inflow; hence, the reservoir could make lower releases. Increasing the flood storage allocation kept the downstream flow entirely within the channel capacity.
2. **Decreased duration of time above downstream channel capacity** – The duration of time that New Don Pedro Reservoir made releases in excess of objective release targets was much shorter; hence, peak reservoir releases were also lower. However, higher releases resulting from an increase in the objective release, when combined with mainstem flows, would offset some of the benefit of lower peak releases.

Similar to other storm frequencies, increasing the objective release lowered the peak flow for large infrequent storms (0.5 and 0.2 percent AEPs), but increased the duration of time that channel capacity would be exceeded. Peak flow would be slightly lowered because a small amount of storage would be evacuated before the large inflow. However, because the inflow was of such a high magnitude, the benefit of additional flood storage allocation would be almost negligible.

Overall, downstream channel benefits were lower when compared to only the allocation of additional flood storage for large storm events.

### ***New Don Pedro Reservoir and Lake McClure Coordinated Operations***

Another operational criteria change explored during the basin-wide sensitivity analysis was operating both New Don Pedro Reservoir and Lake McClure for the same downstream location, the San Joaquin River at Maze Road. This change allowed the flow in the San Joaquin River to remain within the channel capacity slightly longer (by a few hours), but peak flows were higher. This was because the reservoirs held back their releases longer to keep the mainstem within the channel capacity for the earlier parts of a storm; thus, the reservoirs filled their allocated flood storage sooner and had to release more water later in the storm. As a result, this operational criteria change was not further explored in this analysis.

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## 6.0 Reservoir Operational Scenarios Considered

Using preliminary observations from the Phase 1 and 2 analyses, several reservoir operational scenarios were considered for inclusion in the Enhance Flood System Capacity approach. These scenarios were considered based on No Project flood management performance in the Central Valley and basin-wide sensitivity observations, and are described in more detail in the following subsections. Because of the preliminary nature of this analysis, the uncertainty associated with the effects of operational criteria changes, and the needed coordination, operational criteria changes were not moved forward into the State Systemwide Investment Approach aside from changes associated with the Folsom Dam Raise, which is already authorized.

The reservoir operational scenarios considered in the Enhance Flood System Capacity approach includes modification to the reservoir release schedule and flood storage allocation at Lake Oroville (equivalent to an additional 200,000 acre-feet of flood storage), and coordinated operation with New Bullards Bar Reservoir, to reduce flood stages on the Feather River during a 0.5 percent AEP (200-year) flood event. Also, in the San Joaquin River Basin, the State would partner with interested reservoir operators to increase the flood storage allocation at New Don Pedro, Friant, and New Exchequer dams by about 400,000 acre-feet to effectively manage the 1 percent AEP (100-year ) flood event at these reservoirs.

### 6.1 Scenarios Considered

As stated above, the 2012 CVFPP Reservoir Analysis is a preliminary analysis and future studies will need to assess the feasibility of changes in reservoir operational criteria, with consideration of effects on other reservoir purposes, and determine the best method for implementing these changes. The goal of the analysis is to see if there are potential flood management benefits associated with making operational criteria changes; it is not to propose specific changes to any reservoir or to preclude other options in modifying operational criteria.

To demonstrate the potential of reservoir operational criteria changes in the Central Valley, the following scenarios were considered for modeling purposes only:

- Sacramento Scenario
  - Increase Lake Oroville flood storage allocation by 200 TAF
  - Modify Lake Oroville’s release schedule (see Table 6-1)
- San Joaquin Scenario
  - Increase Millerton Lake flood storage allocation by 60 TAF
  - Increase Lake McClure flood storage allocation by 100 TAF
  - Increase New Don Pedro Reservoir flood storage allocation by 230 TAF

These scenarios were considered because they yielded large flood management benefits systemwide. Potential changes reduced peak downstream flow, lowered downstream flow within or near channel capacity for more AEP storms, and decreased the duration of time that flow exceeded the downstream channel capacity.

**Table 6-1. Simplified Lake Oroville Release Schedule Modifications**

No Project Conditions		Scenario Considered	
Reservoir Inflow (cfs)	Required Release (cfs)	Reservoir Inflow (cfs)	Required Release (cfs)
0 – 30,000	15,000	0 – 30,000	15,000
30,000 – 120,000	60,000	30,000 – 120,000	60,000
120,000 – 175,000	100,000	120,000 – 300,000	80,000
> 175,000	150,000	> 300,000	150,000

Key:  
cfs = cubic feet per second

## 6.2 Sacramento River Basin

The Sacramento Scenario targeted modifying reservoir operational criteria in the Sacramento River Basin. Because more than half of Yuba River flow is uncontrolled, the Sacramento Scenario modified the operational criteria at Lake Oroville, on the Feather River. Because Lake Oroville is able to manage 1 and 0.5 percent AEP Sacramento-centered storms, the operational criteria changes focused on lowering reservoir releases by modifying the release schedule. Modifying the release schedule lowered the required reservoir release for a given inflow, thus storing more of the inflow in the reservoir. To offset the increase in stored water, an additional

200 TAF of flood storage was allocated to Lake Oroville's flood storage allocation. Table 6-1 details the changes to the release schedule for Lake Oroville that were considered.

As stated above, modifications to the release schedule focused on lowering average maximum reservoir releases. Under the No Project condition, Lake Oroville releases 100,000 cfs when inflow into the reservoir is between 120,000 cfs and 175,000 cfs, and increases its release to 150,000 cfs when inflow exceeds 175,000 cfs. The Sacramento Scenario proposes changing the specified release from 100,000 cfs to 80,000 cfs for the same inflow range, and delaying the maximum release of 150,000 cfs until inflow exceeds 300,000 cfs. The additional flood storage allocation would be used to store the additional volume of floodflow in the reservoir resulting from decreased releases.

This scenario resulted in not only a lower simulated peak release, but also an overall average lower release during the height of a storm. Inflow into Lake Oroville exceeds 175,000 cfs for 4 percent AEP and less frequent, larger storms (Table 6-2). Hence, under the No Project condition, Lake Oroville could release up to 150,000 cfs during a 4 percent AEP storm. With the Sacramento Scenario, the maximum outflow is limited to 80,000 cfs for up to a 1 percent AEP storm. A maximum outlet capacity of 150,000 cfs would not occur until a 0.5 percent AEP storm.

**Table 6-2. Peak Inflow into Lake Oroville for Sacramento-Centered Storm**

<b>AEP</b>	<b>Peak Inflow<sup>1</sup> (cfs)</b>
50 percent	125,000
10 percent	190,000
4 percent	237,000
2 percent	295,000
1 percent	353,000
0.5 percent	441,000

Note:

<sup>1</sup> Peak inflow is rounded to the nearest thousand.

Key:

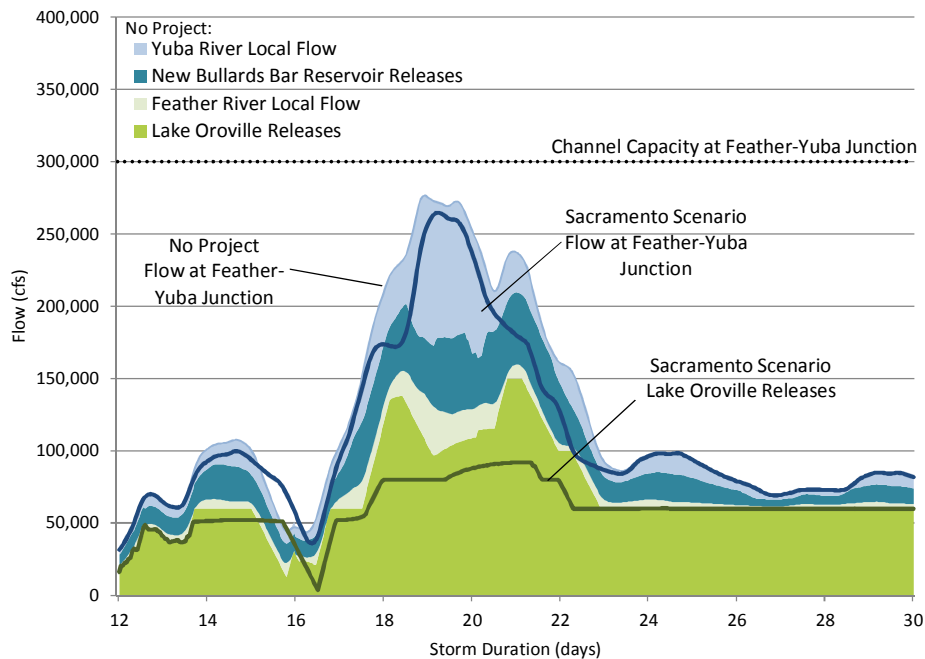
AEP = annual exceedence probability

cfs = cubic feet per second

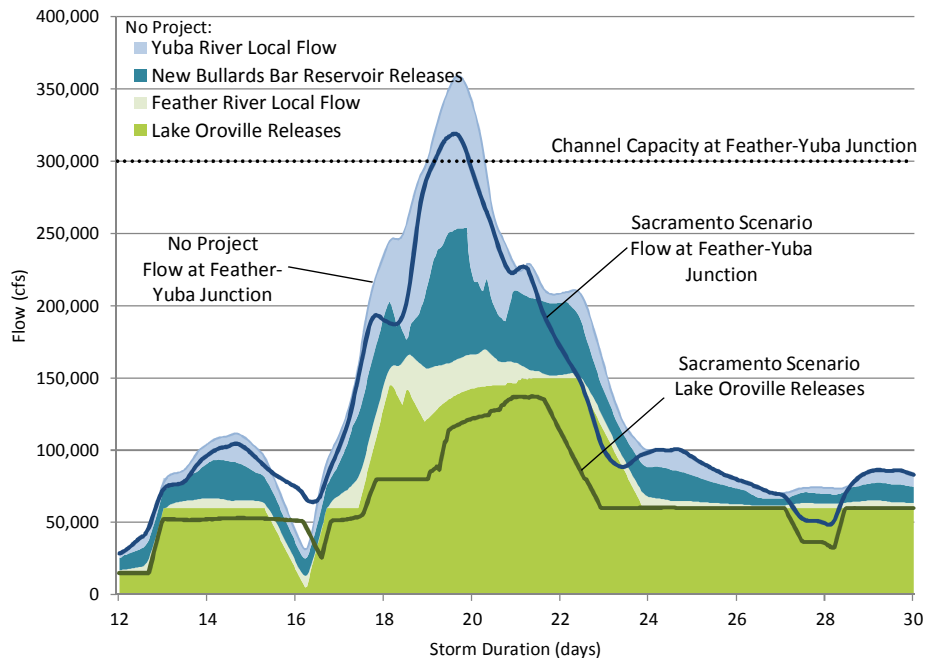
Figure 6-1 shows that the simulated peak release from Lake Oroville decreased by nearly 70,000 cfs (from 150,000 cfs to 81,182 cfs) for a 1 percent AEP Sacramento-centered storm. In addition, average reservoir releases above 60,000 cfs decreased from approximately 111,000 cfs to 78,000 cfs. This resulted in lower flow at the confluence of the Feather and Yuba rivers and the number of channel flow peaks decreasing from two to one. The Sacramento Scenario also lowered the simulated peak flow farther downstream at Nicolaus (downstream from the confluence of the Bear and Feather rivers) by 40,000 cfs. The simulated peak flow, however, remained above the 320,000 cfs channel capacity at Nicolaus, at 380,026 cfs, for a 1 percent AEP storm.

The Sacramento Scenario also lowered peak downstream flows for a 0.5 percent AEP storm (Figure 6-2). While downstream channel capacity on the Feather River was still exceeded, the simulated peak flow rate decreased by 40,000 cfs at the confluence of the Feather and Yuba rivers.

Downstream from the confluence of the Feather River with the Sacramento River at the Fremont Weir, the effect of the Sacramento Scenario on Sacramento River flows was minimal (approximately a 1 percent change in flow). Flow in the mainstem slightly increased in some locations (e.g., I Street gage). This was because the volume of water diverted from the Sacramento River to the Yolo Bypass depends on the flow upstream from the bypass. If there is less flow upstream from the bypass, then less water is diverted into the Yolo Bypass; hence, more water could remain in the mainstem.



**Figure 6-1. Simulated Effects of Lake Oroville Operational Criteria Changes at Feather-Yuba River Junction for 1 Percent AEP Sacramento-Centered Storm**



**Figure 6-2. Simulated Effects of Lake Oroville Operational Criteria Changes at Feather-Yuba River Junction for 0.5 Percent AEP Sacramento-Centered Storm**

Table 6-3 summarizes simulated effects on the Sacramento River Basin as a result of the Sacramento Scenario operational criteria changes to Lake Oroville.

While this scenario has flood management benefits, operational criteria changes to Lake Oroville may affect its other purposes (i.e., water supply, fisheries). Potential effects of reservoir operational criteria are discussed in Section 8.

**Table 6-3. Simulated Effects of Sacramento Scenario on Peak Flow for Sacramento-Centered Storm**

Index Point	Overall Effect on Peak Flow	Simulated Decrease in Peak Flow (cfs) (percent)			
		1 Percent AEP		0.5 Percent AEP	
Lake Oroville	Decrease	57,922	(39)	12,711	(8)
Feather and Yuba River Junction	Decrease	12,031	(4)	40,091	(11)
Feather River at Nicolaus	Decrease	12,551	(4)	40,077	(10)
Sacramento and Feather River Junction	Decrease	13,480	(3)	43,016	(7)
Sacramento River near I Street Gage	Increase	-638	(-1)	-1,291	(-1)

Model: HEC-5

Key:

AEP = annual exceedence probability

cfs = cubic feet per second

## 6.3 San Joaquin River Basin

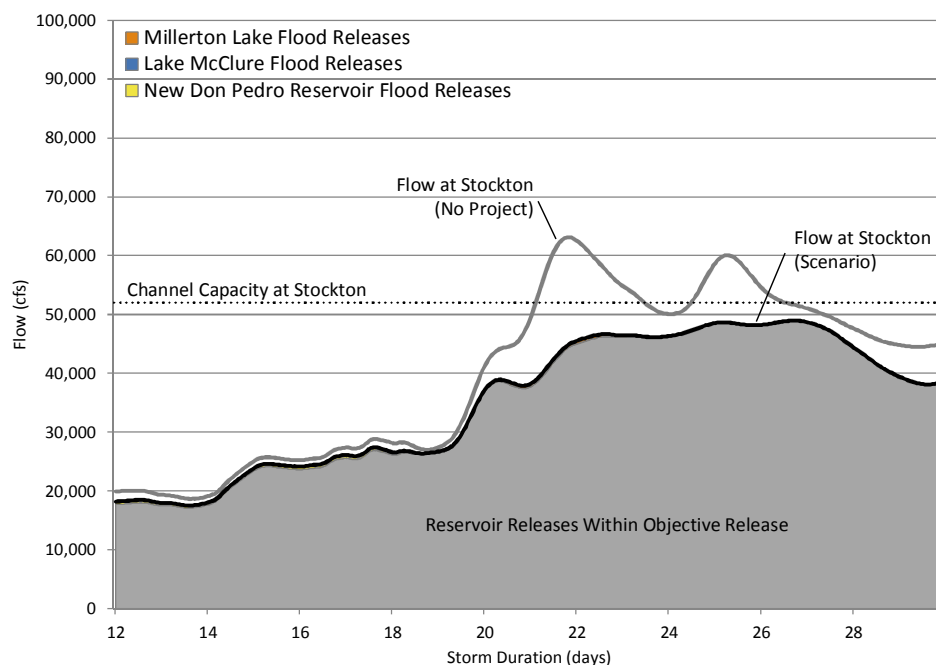
The San Joaquin Scenario explored modifying required storage for flood management at Millerton Lake, Lake McClure, and New Don Pedro Reservoir. These three reservoirs were modified because they exceed their objective release during 1 percent AEP Vernalis-centered storms. Increasing the allocated volume of flood storage enabled the reservoirs to operate within their objective releases more frequently, decreasing channel flow downstream.

While New Don Pedro Reservoir experiences the largest amount of inflow in excess of available current flood storage, Millerton Lake and Lake McClure also contribute to above-channel-capacity flows at Stockton for 1 percent AEP and less frequent storms. To reduce both the magnitude and duration of time that channel capacity would be exceeded at Stockton, the San Joaquin Scenario increased the flood storage allocation at Millerton

Lake, Lake McClure, and New Don Pedro Reservoir by 60 TAF, 100 TAF, and 230 TAF, respectively.

The volume of additional flood storage allocation selected for the San Joaquin Scenario was based on the volume of inflow in excess of available current flood storage that could not be managed for a 1 percent AEP Vernalis-centered storm (see Figure 4-4), and the basin-wide sensitivity analysis showed that the largest benefit occurred with this volume of additional storage (see Figure 5-4).

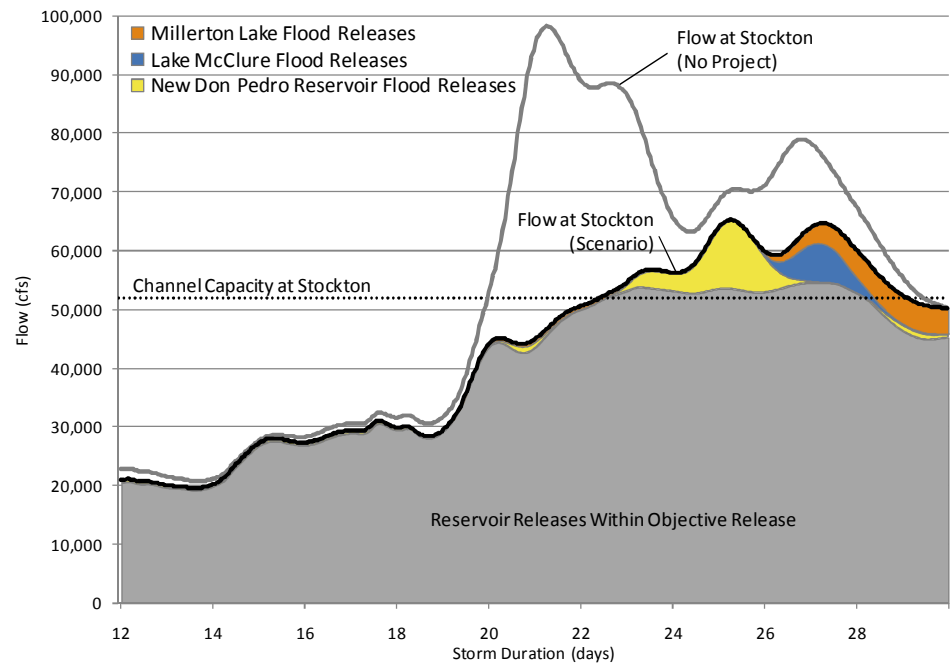
Figure 6-3 shows that the San Joaquin Scenario changes enabled the reservoirs to operate within their objective release throughout the duration of the 2 percent AEP Vernalis-centered storm. As a result, the flow at Stockton was within its channel capacity.



**Figure 6-3. San Joaquin Scenario Simulated Reservoir Contributions to Flow at Stockton for 2 Percent AEP Vernalis-Centered Storm**

For a 1 percent AEP Vernalis-centered storm, the three reservoirs generally operated within their objective releases during the beginning of the storm, removing the large first peak under the No Project condition (Figure 4-6). Nevertheless, the additional flood storage allocation was insufficient to prevent all flood releases. With changes in San Joaquin Scenario operational criteria, the highest peak flow at Stockton was reduced to 64,000 cfs. New Don Pedro Reservoir was the only reservoir that contributed flood releases during this highest peak flow at Stockton,

although a similar peak 2 days later was caused by flows from Millerton Lake and Lake McClure.



**Figure 6-4. San Joaquin Scenario Simulated Reservoir Contributions to Flow at Stockton for 1 Percent AEP Vernalis-Centered Storm**

The simulated effects of the San Joaquin Scenario on peak flows at various locations throughout the San Joaquin River Basin are summarized in Table 6-4.



**Table 6-4. Simulated Effects of San Joaquin Scenario on Peak Flow for Vernalis-Centered Storm**

Index Point	Overall Effect on Peak Flow	Simulated Decrease in Peak Flow (cfs) (percent)			
		2 Percent AEP		1 Percent AEP	
Chowchilla Bypass near Fresno River	Decrease	1,967	(16)	7,260	(30)
El Nido	Decrease	2,121	(10)	8,753	(24)
Near Newman	Decrease	1,993	(6)	15,402	(25)
At Maze Road Bridge	Decrease	15,733	(29)	34,918	(38)
Near Vernalis	Decrease	15,241	(24)	34,377	(35)
Stockton	Decrease	14,173	(22)	32,924	(34)

Model: HEC-5

Key:

AEP = annual exceedence probability

cfs = cubic feet per second



## 7.0 Effects of Operational Criteria Changes

This section discusses simulated flood management effects of the three reservoir operational scenarios considered, and then briefly discusses qualitatively other reservoir water uses and purposes.

### 7.1 Flood Management Benefits

The main objective of the 2012 CVFPP Reservoir Analysis was to determine whether changes to reservoir operational criteria could improve coordination among the reservoirs in the Central Valley flood management systems, thereby lowering downstream peak stage. Because HEC-5 does not take into account hydraulic conditions (e.g., unsteady flow, levee breaks), UNET was used to provide a more realistic estimate of riverine flow conditions resulting from reservoir operational criteria changes. Changes in the peak water surface elevation (stage) and volume of out-of-system flow were used to compare the simulated effects of reservoir operational criteria changes.

To compare the stage reduction, stage-frequency curves were generated at a series of locations throughout the Central Valley flood management systems. Peak stages for each storm AEP were connected to generate a stage-frequency curve for a given location. While not done in this reconnaissance-level analysis, stage-frequency curves can be used as inputs into an economic model, such as HEC-FDA, to quantify economic benefits associated with stage reduction.

A decrease in stage could result from (1) less water being released from reservoirs, or (2) an increase in water leaving a channel through an increase in levee failures. As a result, the volume of overland flow was quantified to better compare the effects of reservoir operational criteria changes.

The following flood management benefits resulting from the operational criteria scenarios considered were observed:

- In the Sacramento River Basin (Sacramento Scenario):
  - The largest decreases in peak stage occurred for 1 percent AEP or more frequent storm events.

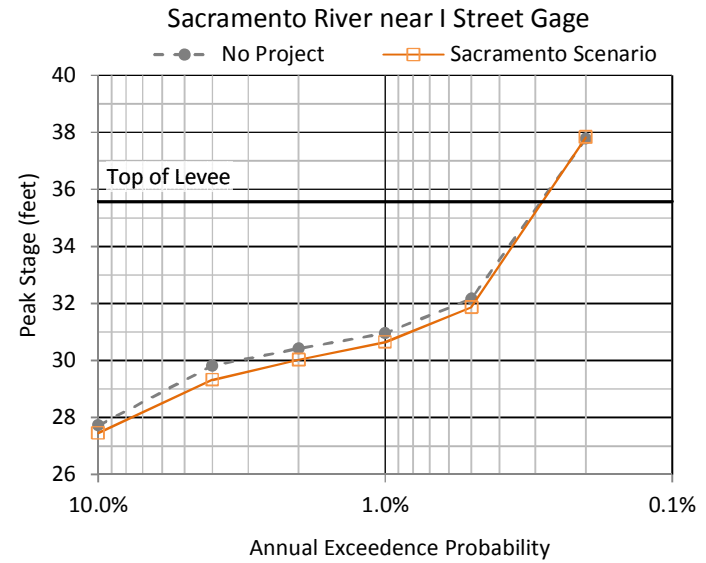
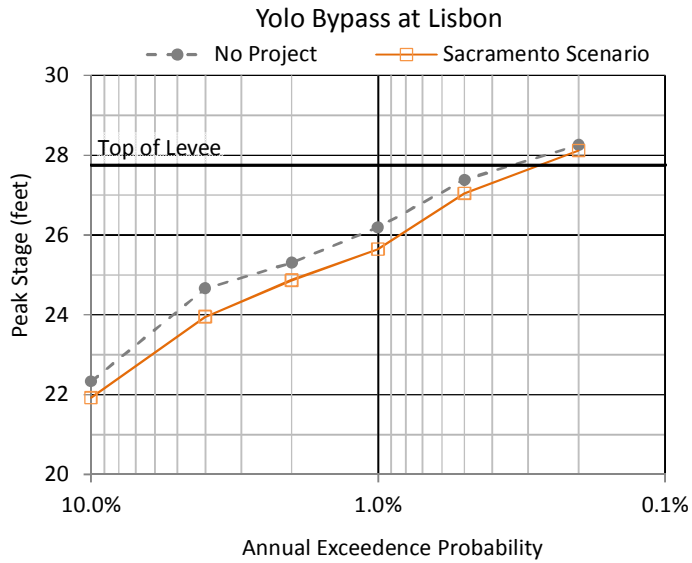
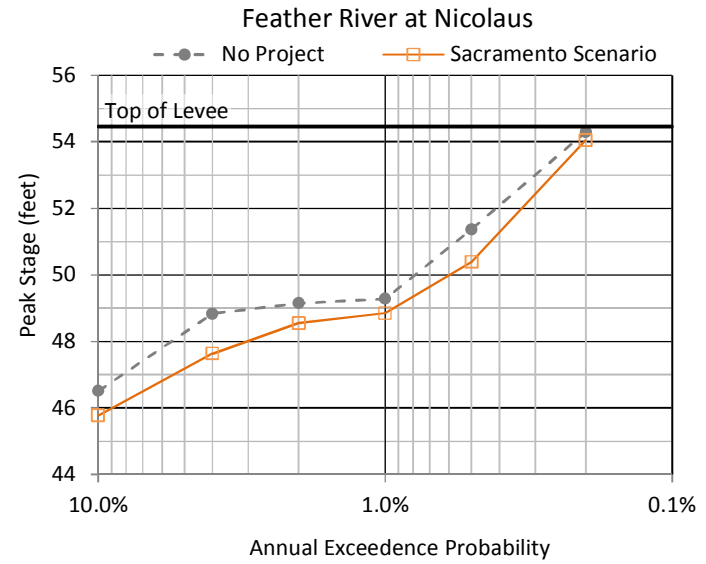
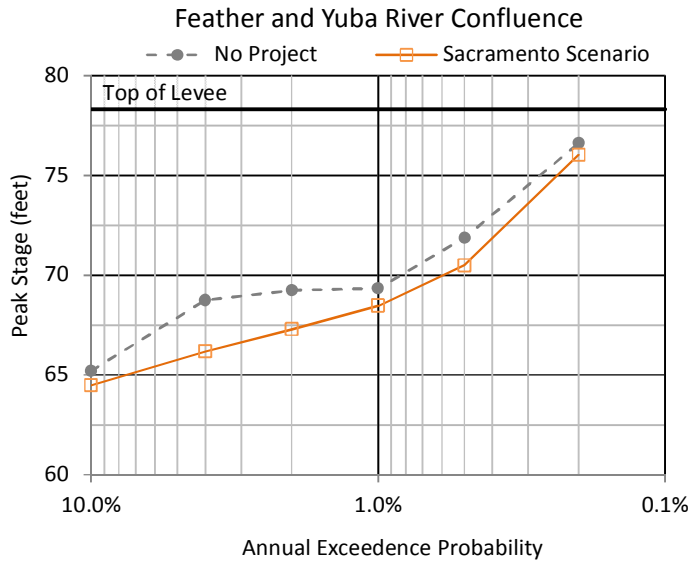
- For the 1 percent AEP Sacramento-centered storm, the total volume of out-of-channel flow decreased by 13 percent (146 TAF).
- The largest flood management benefit was realized in small to midsized storm events (4, 2, and 1 percent AEP storms).
- In the San Joaquin River Basin (San Joaquin Scenario ):
  - The largest decreases in peak stage occurred for 2 percent AEP or less frequent storm events.
  - The decrease in out-of-channel volume ranged from 15 percent to 39 percent (40 TAF to 206 TAF) for midsized to large-sized storm events (2, 1, and 0.5 percent AEP storms).

### **7.1.1 Sacramento River Basin**

The Sacramento Scenario lowered the peak stage in the Feather River Basin and lower Sacramento River Basin (Figure 7-1).

Changing Lake Oroville's operational criteria lowered the peak stage at the Feather-Yuba River confluence, the Feather River at Nicolaus, and the Sacramento River at the I Street gage by 1 percent (nearly 1 foot) for a 1 percent AEP storm. The peak stage at the Yolo Bypass near Lisbon decreased by 2 percent (0.5 foot) for a 1 percent AEP storm.

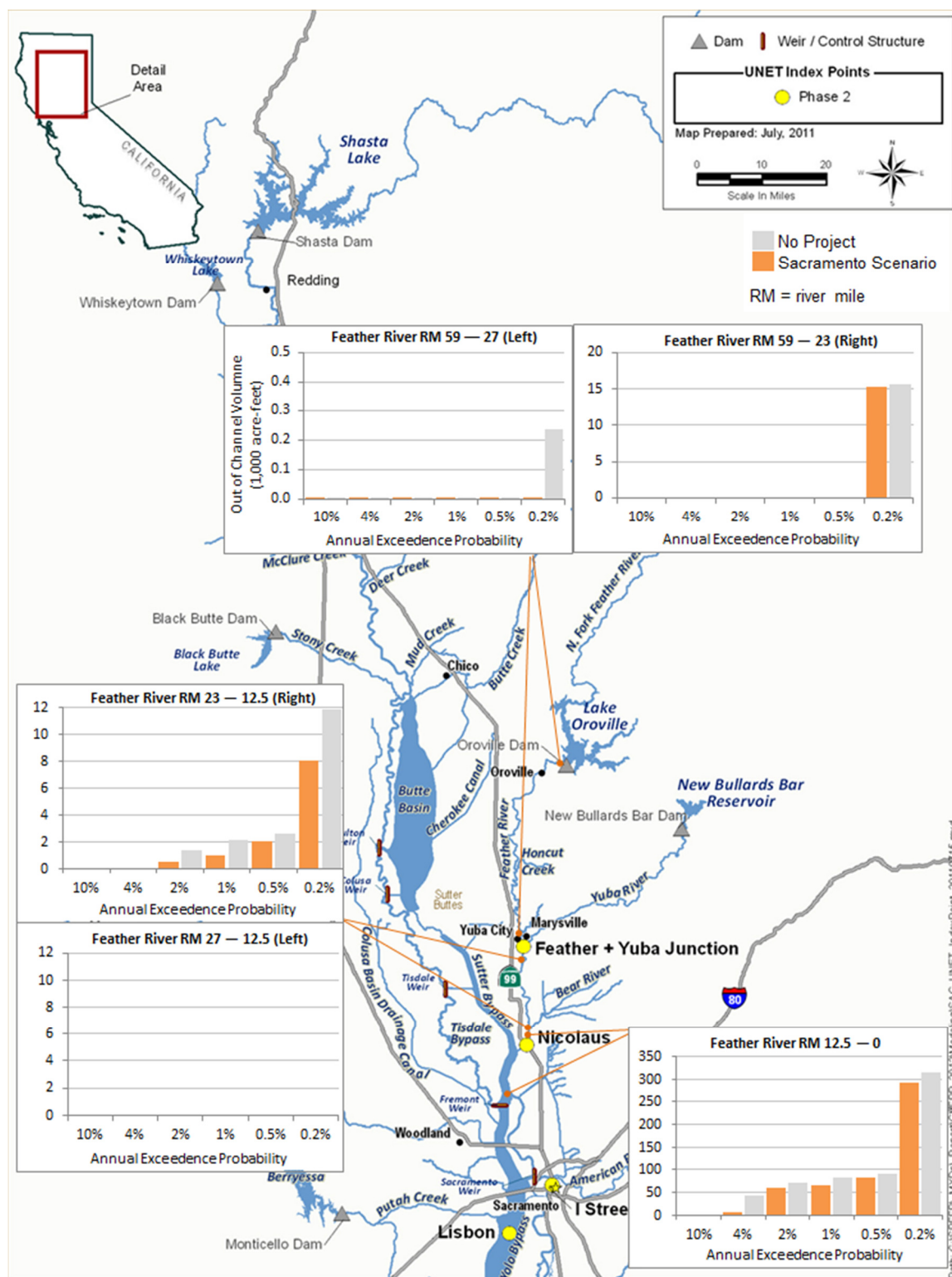
In addition to decreases in stage, the volume of out-of-channel flow decreased. Figures 7-2 and 7-3 show out-of-channel flow by reach. Throughout the Feather River, overall out-of-channel flow decreased for all storms. In the 60-mile reach of the Sacramento River downstream from the Sacramento Weir, out-of-channel flow was nearly eliminated for the 2 percent AEP Sacramento-centered storm. Figure 7-4 shows how the volume of out-of channel flow decreased throughout the entire Sacramento River Basin.



Model: UNET

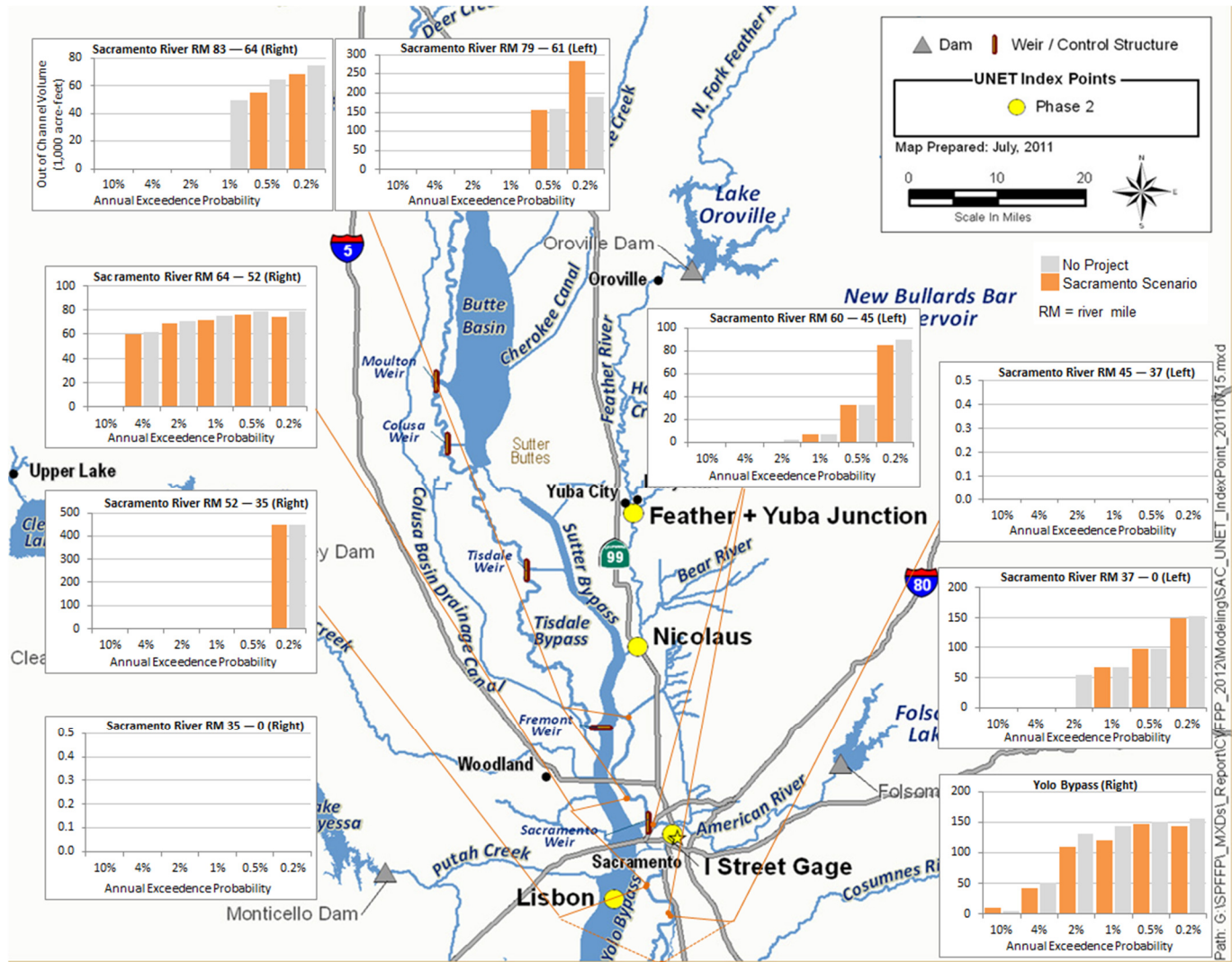
**Figure 7-1. Sacramento Scenario Stage-Frequency Curves for Sacramento-Centered Storm at Feather-Yuba River Confluence, Feather River at Nicolaus, Yolo Bypass at Lisbon, and Sacramento River at I Street Gage**

**2012 Central Valley Flood Protection Plan  
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Model: UNET

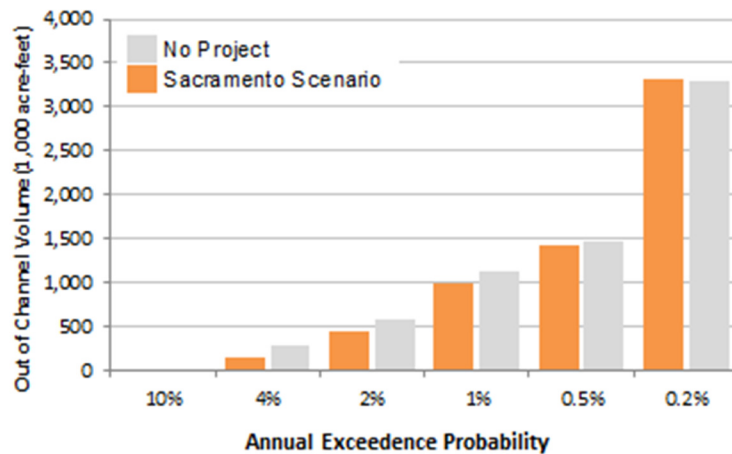
**Figure 7-2. Sacramento Scenario Volume of Out-of-Channel Flow for Sacramento-Centered Storm Along Feather River (1,000 acre-feet)**



Model: UNET

Note: Dotted lines represent that river miles extend past the map extents.

**Figure 7-3. Sacramento Scenario Volume of Out-of-Channel Flow for Sacramento-Centered Storm Along Lower Sacramento River (1,000 acre-feet)**



**Figure 7-4. Sacramento Scenario Total Sacramento River Basin Out-of-Channel Flow Reductions**

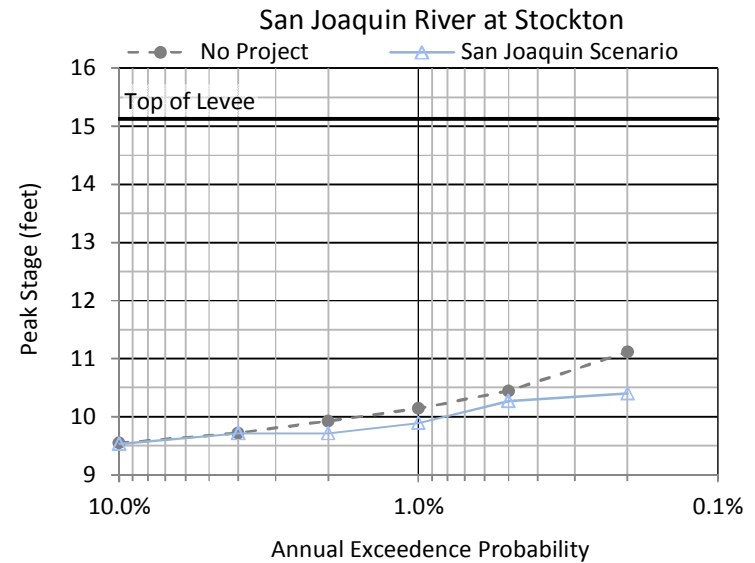
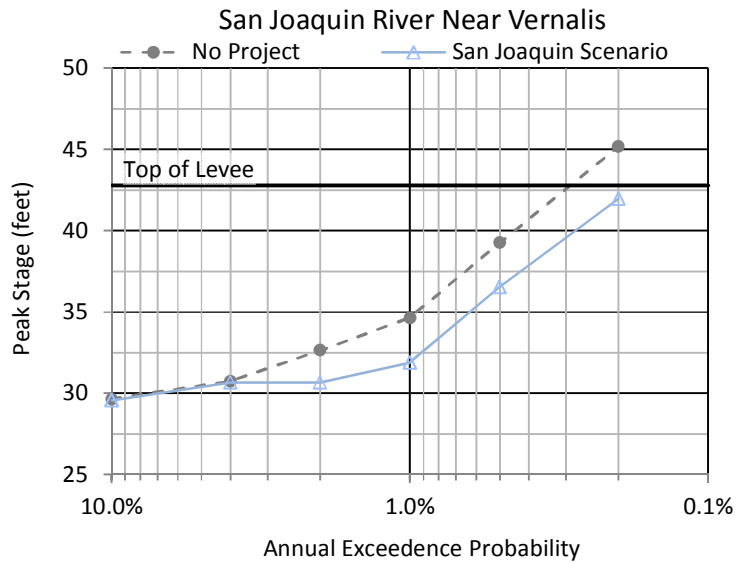
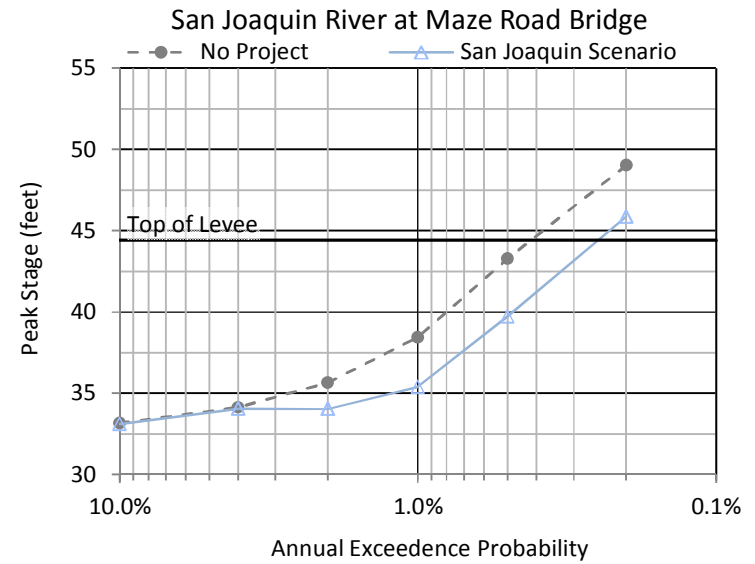
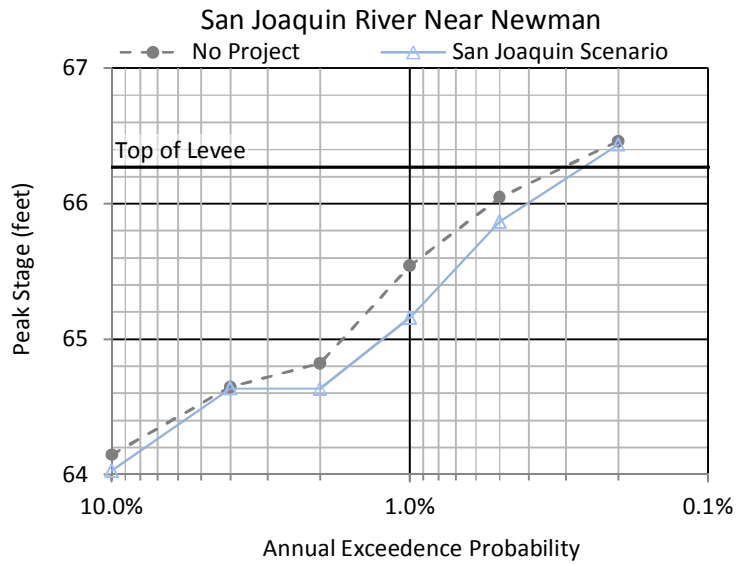
### 7.1.2 San Joaquin River Basin

The San Joaquin Scenario decreased the peak stage throughout the San Joaquin River Basin. Figure 7-5 shows the simulated decrease in stage at various locations along the lower San Joaquin River.

The peak stage on the San Joaquin River at Newman was slightly decreased by an average 0.2 percent from No Project conditions for all Vernalis-centered AEP storms because of influences from increased flood storage allocation at Millerton Lake and Lake McClure. At Stockton, the simulated peak stage for the 0.5 and 0.2 percent AEP storms was nearly the same (less than 0.03-foot difference).

In addition to decreases in stage, the volume of out-of-channel flow throughout the entire San Joaquin River Basin also decreased. Figure 7-6 shows the out-of-channel flow by reach and Figure 7-7 shows the total out-of-channel flow. In the 14-mile reach downstream from Vernalis, the out-of-channel flow was nearly eliminated for the 1 percent AEP Vernalis-centered storm. For the 0.5 percent AEP storm, out-of-channel flow decreased by 77 TAF for the San Joaquin Scenario. The volume of out-of-channel flow did increase for in the downstream portion of the San Joaquin River for some AEP storms, but the volume decreased in the Chowchilla and Eastside bypasses; overall, the net change in out-of channel flow was a decrease.

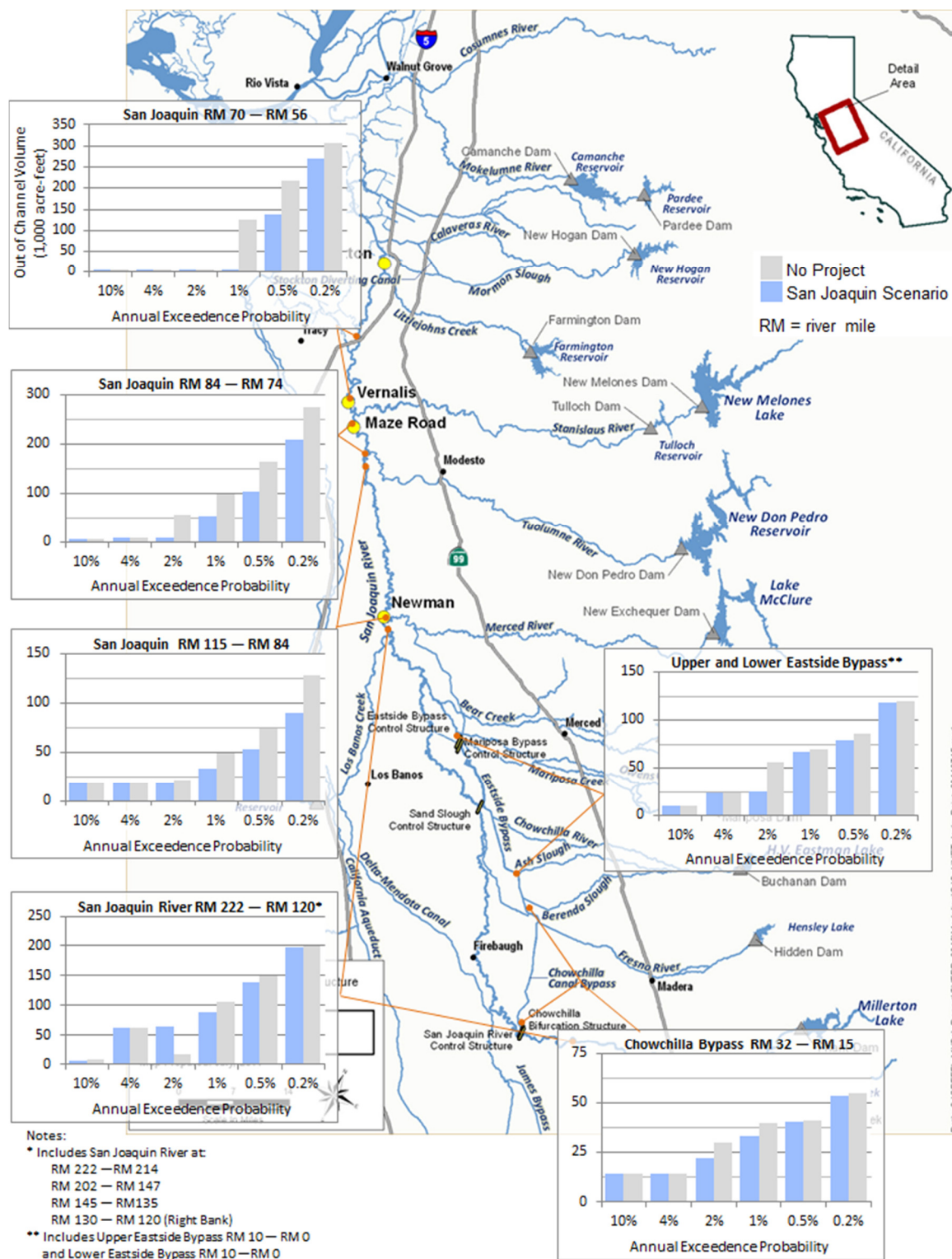




Model: UNET

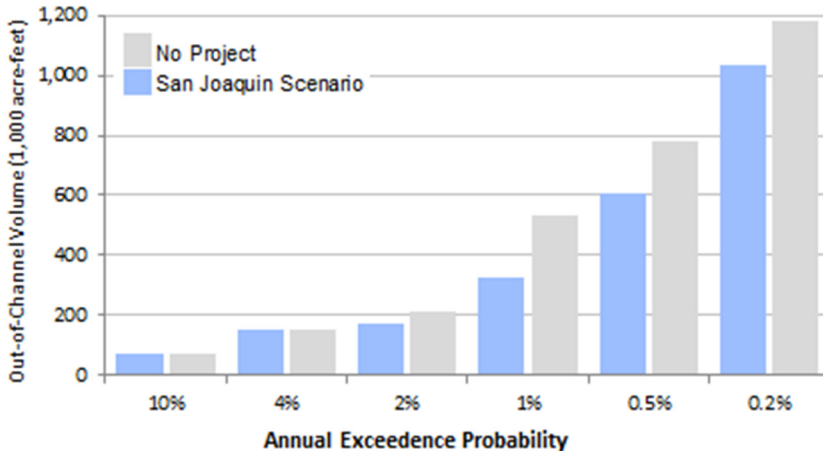
**Figure 7-5. San Joaquin Scenario Stage-Frequency Curves for Vernalis-Centered Storm at San Joaquin River near Newman, at Maze Road Bridge, near Vernalis, and at Stockton**

# 2012 Central Valley Flood Protection Plan Attachment 8B: Reservoir Analysis



Model: UNET

**Figure 7-6. San Joaquin Scenario Volume of Out-of-Channel Flow for Vernalis-Centered Storm**



**Figure 7-7. San Joaquin Scenario Total San Joaquin River Basin Out-of-Channel Flow**

## 7.2 Other Reservoir Water Uses

Aside from providing flood management benefits, changing operational criteria for flood damage reduction could affect a multitude of other reservoir water uses and purposes. Adjusting the amount of flood storage and magnitude of objective releases may alter the volume of reservoir storage available for peak season water uses. This may result in economic effects on the following:

- Water supply reliability
- Hydropower generation
- Recreational opportunities
- Groundwater storage
- Instream requirements

### 7.2.1 Water Supply Reliability

In addition to flood management, water supply is one of the major purposes for multipurpose reservoirs in the Central Valley. The majority of precipitation in California falls between October and March; therefore, changes to reservoir operational criteria for peak flow reduction are focused on that period. Changes in reservoir flood space allocation and objective release during the wet season could alter the ability of a reservoir to fill by the end of the wet season and to be ready to meet water supply demands, which generally peak in summer months. On the basis of a high level appraisal, the impacts to water supply reliability resulting from operational criteria changes considered in this analysis could possibly be

effectively mitigated; a more detailed analysis to better quantify benefits to flood management and potential adverse impacts and associated mitigation is needed.

### **7.2.2 Hydropower Generation**

Hydropower generation depends on elevation of the water in a reservoir (i.e., head). Changes to reservoir operational criteria would alter reservoir storage and available head in a reservoir during flood season and possibly during other times of the year (if the reservoir does not fill as a result of operational criteria changes), and thus decrease power generation and revenue. In addition, alternative sources of energy may be needed to account for any changes. The magnitude of the economic cost to hydropower could be determined from factors such as net generation of power and power market prices.

### **7.2.3 Recreational Opportunities**

Many of the Central Valley multipurpose reservoirs are major recreational venues. A study performed by DWR on recreational sites in Northern California estimated that 2.5 million people visit Northern California lakes and reservoirs per year (DWR, 2004). Recreational opportunities are proportional to reservoir water surface area. In general, the greater the surface area, the more recreational activities are available. Changes to reservoir operational criteria would alter reservoir storage during flood season and other times of the year (if the reservoir did not fill as a result of operational criteria changes), and thus change water surface area. Aquatic recreational activity is especially sensitive to such changes. The value of economic effects would depend on season, type of recreational activities, etc.

### **7.2.4 Groundwater Storage**

Changes in water supply availability from a reservoir could vary the use of other water supplies, such as groundwater. A change in groundwater pumping would affect regional groundwater storage conditions and, thus, access to groundwater by other parties could change. Also, interaction between surface water and groundwater could differ. Modifying the amount of space required for flood storage may alter the timing and magnitude of flows released from a reservoir. Reservoir water and groundwater could be used conjunctively to increase water supply while keeping space available in the reservoir for flood retention.

### **7.2.5 Instream Requirements**

Reservoirs are also often operated to meet various requirements for fisheries, vegetation, wildlife, water quality, etc. Changes to reservoir

operational criteria during the wet season could alter water availability to meet these requirements and, thus, have an economic impact.

Modifying reservoir operational criteria may affect anadromous fish survival and reproduction rates by altering seasonal water flows and temperatures in the Sacramento and San Joaquin rivers. For example, altering river hydraulics may affect the flows required to move juvenile salmonids through the system. Changes in water temperatures, potentially resulting from a reduction in surface storage during critical periods, may affect salmon production. This change may also have an economic effect on recreational and commercial fishing for certain species.

Vegetation and wildlife may be affected if implementing any of these scenarios changes riparian habitat, modifies sensitive natural communities, affects federally protected wetlands, or conflicts with local policies, ordinances protecting biological resources, and adopted habitat conservation plans. For example, native riparian and wetland plants may be affected because changes in objective flows could potentially change the duration of time and frequency that current vegetation is submerged.

Changes in reservoir operational criteria also may affect water quality parameters such as pH, dissolved oxygen, turbidity, salinity, and temperature. These changes may alter treatment requirements for water supplies, crop yields for sensitive crops, amounts of sedimentation in canals, etc.

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## 9.0 Acronyms and Abbreviations

1-D .....	one-dimensional
AEP .....	annual exceedence probability
BO .....	Biological Opinion
Board .....	Central Valley Flood Protection Board
cfs .....	cubic feet per second
Comprehensive Study .....	Sacramento and San Joaquin River Basins Comprehensive Study, California
CU .....	Conjunctive Use
CVFPP .....	Central Valley Flood Protection Plan
CVP .....	Central Valley Project
Delta .....	Sacramento-San Joaquin Delta
DWR .....	California Department of Water Resources
ESRD .....	Emergency Spillway Release Diagram
F-BO .....	Forecast-Based Operations
F-CO .....	Forecast-Coordinated Operations
FEMA .....	Federal Emergency Management Agency
FERC .....	Federal Energy Regulatory Commission
FPO .....	Folsom Dam Permanent Operations
FWUA .....	Friant Water Users Authority
HEC .....	Hydrologic Engineering Center
ID .....	Irrigation District
JFP .....	Joint Federal Project
NMFS .....	National Marine Fisheries Service
NOAA .....	National Oceanic and Atmospheric Administration
PEIS/R .....	Program Environmental Impact Statement/Report
Reclamation .....	U.S. Department of the Interior, Bureau of Reclamation
RO .....	Reservoir Operations
ROD .....	Record of Decision
SAC .....	Sacramento

SAFCA ..... Sacramento Area Flood Control Agency  
SJQ ..... San Joaquin  
SJRRP ..... San Joaquin River Restoration Program  
SPFC ..... State Plan of Flood Control  
SWP ..... State Water Project  
TAF ..... thousand acre-feet  
USACE..... U.S. Army Corps of Engineers  
USFWS ..... U.S. Fish and Wildlife Service  
V9B ..... Version 9B  
YCWA ..... Yuba County Water Agency



